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DTU Space
National Space Institute
Technical University of Denmark

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ESA CryoVEx 2011

Airborne field campaign with ASIRAS radar, EM induction sounder and laser scanner

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ABSTRACT

After the successful launch of CryoSat-2 in April 2010, the first direct Arctic validation campaign of the satellite was carried out in the period April 15 - May 8, 2011. This report describes the airborne part of the CryoSat Validation Experiment (CryoVEx) 2011, and includes;

1) Data collected with the ESA airborne Ku-band interferometric radar (ASIRAS), coincident airborne laser scanner (ALS) and vertical photography to acquire data over sea- and land ice along CryoSat-2 ground tracks. The airborne campaign was coordinated by DTU Space using the Norlandair Twin Otter (TF-POF).

2) Sea ice thickness data obtained with an airborne electromagnetic (AEM) induction sounder conducted by Alfred Wegener Institute (AWI) with fixed-wing airplane (Polar-5, Basler BT-67).

DTU Space airborne team visited five main validation sites: Devon ice cap (Canada), Austfonna ice cap (Svalbard), the EGIG line crossing the Greenland Ice Sheet, as well as the sea ice north of CFS Alert (Ellesmere Island), and sea ice north off Svalbard. Selected tracks were planned to match CryoSat-2 passes and a few of the sea ice flights out of CFS Alert were coordinated with AWI Polar-5 carrying the AEM induction sounder and NASA's Operation IceBridge P-3 carrying a variety of instruments for sea ice and snow retrieval. At each validation site ground teams measured ice and snow properties, and raised corner reflectors acting as a surface reference point to estimate the penetration depth of the ASIRAS radar. This report describes in details the airborne systems, together with campaign implementation plan, data processing and data quality analysis.

The CryoVEx 2011 campaign was a success and the processed data is of high quality. The datasets are very important in order to understand the CryoSat-2 radar signals over sea- and land ice.

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NAME OF ESA STUDY MANAGER	**ESA BUDGET HEADING**
Malcolm Davidson Mission Science Division Validation Campaigns - ESTEC	

Table of Contents

1 Introduction

The overall purpose of ESA' CryoSat Validation Experiment (CryoVEx) 2011 was, for the first time, to directly validate the measurements from CryoSat-2, through a coordinated major effort involving a large group of European, Canadian and US scientist. One primary aim of the CryoVEx 2011 campaign is to provide data which can allow the optimal recommendation from the CVRT (CryoSat Validation and Retrieval Team), as to the optimal Level 1b and Level 2 retrieval algorithms, with which to reprocess the CryoSat-2 data.

This report focuses primarily on:

1. Data collected with the ESA airborne ku-band interferometric radar (ASIRAS), coincident airborne laser scanner (ALS) and vertical photography to acquire data over sea- and land ice. The airborne campaign was coordinated by DTU Space using the Norlandair Air Twin Otter (TF-POF), which is the same aircraft as used in former CryoVEx campaigns, where it was owned by Air Greenland.
2. Sea ice thickness data obtained with airborne electromagnetic (AEM) induction sounding conducted with a fixed-wing airplane (Polar-5, Basler BT-67) of the Alfred Wegener Institute.

The airborne work was coordinated to match CryoSat-2 ground tracks, and overflights of ground work at CryoVEx validation sites. The groundtracks including non-ESA flights are presented in Figure 1 with the validation sites marked by red circles. This includes sea ice measurements in Lincoln Sea out of Canadian base Alert, Ellesmere Island, and in the Fram Strait near research vessel RV Lance. Land ice measurements were aquired along the EGIG line across the Greenland ice sheet, together with Austfonna and Devon ice caps.

At each validation site ground teams measured ice and snow properties, and raised corner reflectors (CR) acting as a surface reference point in order to estimate the penetration depth of the ASIRAS radar. The CryoVEx 2011 campaign objectives is outlined in detail in the ESA CryoVEx 2011 Campaign Implementation Plan (editors: T. Pearson, M. Wooding).

This report outlines the airborne field operations and the processing of the data acquired during the CryoVEx 2011 campaign. In addition examples from the processed datasets are presented, together with first results of intercomparison of CryoSat-2 level 2 data and airborne data.

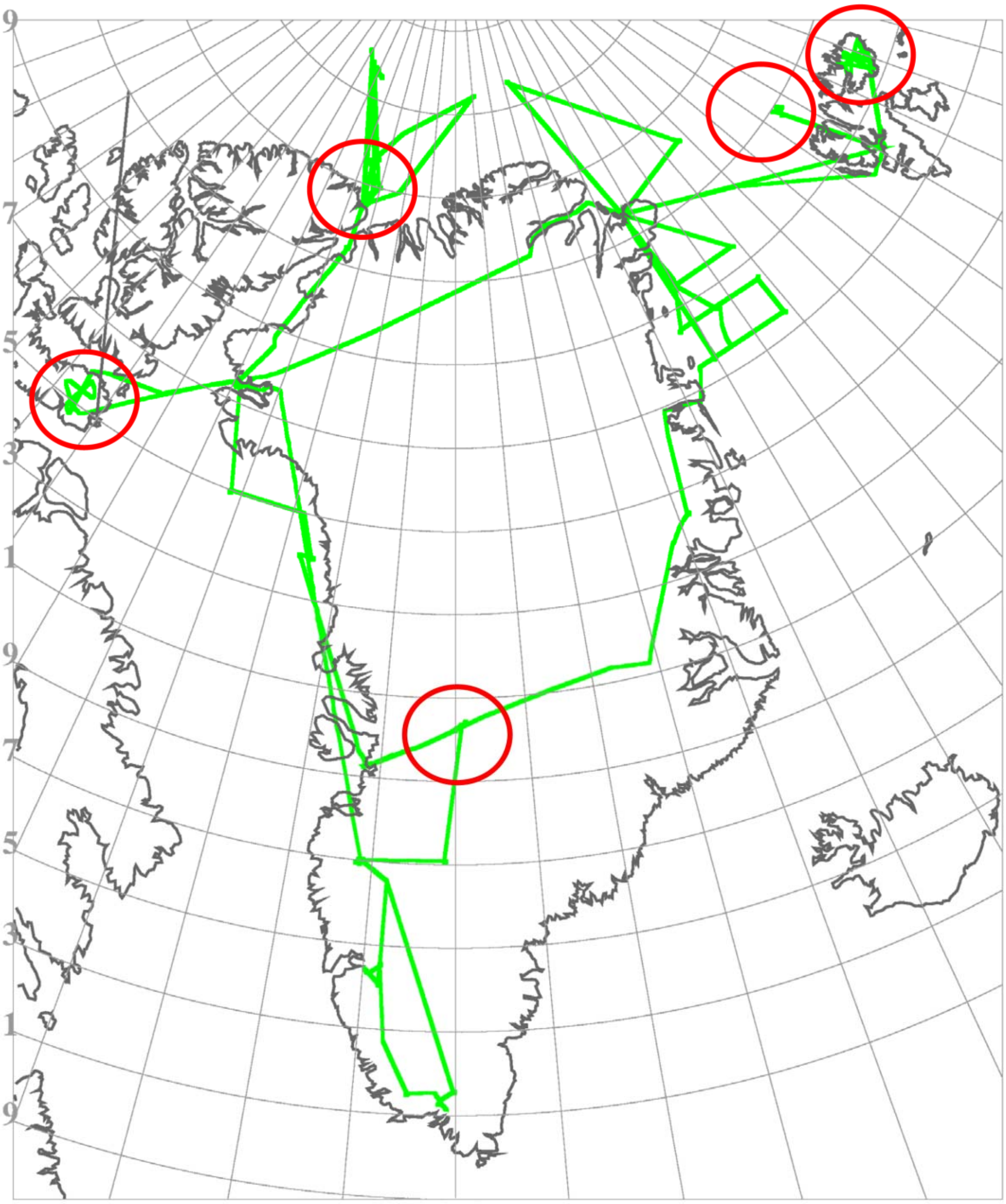


Figure 1: Overview of the flight tracks (green lines) from the CryoVEx 2011 campaign including non-ESA flights. The five main validation sites are marked by red circles

2 Airborne laser scanner (ALS) and radar (ASIRAS)

2.1 Summary of operation

Due to logistics of the various field teams the CryoVEx airborne campaign was split in two operational periods. Based on experience from earlier CryoVEx campaigns the activities carried out from the Canadian base CFS Alert on Ellesmere Island were planned to take place early in the season to make sure the weather was more stable (fog had delayed many flights in earlier CryoVEx campaigns from Alert) and to ensure cold conditions of the sea ice itself (target temperatures of -20^{o}C or below). Thus, access to Alert was acquired during operation Boxtop on April 12-19 to cover the sea ice activities out of Alert. The second part of the campaign was carried out on April 26 – May 9 to cover the sea ice work north of Svalbard, as well as the ice caps (Austfonna and Devon) and the Greenland ice sheet (EGIG line).

In the intervening period April 20-25 the Twin Otter was used in Southern Greenland for a national project, PROMICE, funded by the Danish Ministry of Climate and Energy initiated to monitor the thickness of the Greenland Ice Sheet, as an ongoing effort to assess changes in its mass budget. And to support test of ESA's airborne ice sounding radar POLARIS.

Additionally, ASIRAS and ALS data were collected whenever possible on the transit flights, including Fram Strait and Baffin Bay to obtain sea ice information for the Greenland Bureau of Mineral and Petrol (BMP). Results of these flights are presented in Pedersen et al (2011).

The installation process, planned to start on April 7, was delayed until April 9 by the re-certification of the aircraft, which was sold from Air Greenland to Norlandair, Iceland, in January 2011. The formal transfer of the aircraft to the new Iceland registration (TF-POF), was done in the very last days prior to the initiation of the CryoVEx 2011 campaign and delayed the arrival of the aircraft in Kangerlussuaq a few days.

Thus, the installation took place April 9-11 in Kangerlussuaq, and included a test flight in the area. Installation and test of the ASIRAS, were performed by experienced staff from Radar System Technique (RST), and found to work perfectly well. Unfortunately, the ALS (Riegl LMS Q-240i), also used in CryoVEx 2008, did not work properly during the installation, even though it was tested prior to shipment in the laboratory in Copenhagen. After conference with specialists from the producer Riegl, the ALS was shipped to Riegl in Austria, for inspection and returned for the second part of the campaign (April 26-May 9). A spare ALS (Riegl LMS Q-140i) was installed during the first part of the CryoVEx 2011 campaign (April 9-25). This was identical to the ALS used through former CryoVEx campaigns (2006, 2004 and 2003).

Despite of the delay, the airborne team arrived in Alert on April 13, just as the weather cleared. The airborne program was finalized within the following four days (April 14-17), including survey of the three validation sites put up by the ground team, and two underflights of CryoSat-2 passes in formation flight with the AWI DC-3 (Polar-5) towing an electromagnetic (EM) sounder below the aircraft, see Chapter 3. The formation flight with the DC-3 worked excellent, as the aircrafts basically could keep the same groundspeed (100 knots). This is an easy setup compared to earlier campaigns, where coordinated flights were made with a helicopter borne EM-system. NASA's Icebridge P-3 carrying multiple sensors for sea ice and snow retrieval was also flying part of the CryoSat track on April 15, see preliminary science flight report attached in Appendix 10. Due to the extreme cold temperature (-20 to -30^{o}C) in Alert, the integrated heaters of the spare ALS (Q-140i) could not keep the system warm for operation. External heating in the morning and foam paddings kept the system running, however, few of the flights out of Alert were flown without ALS, see also Section 2.5.3.

The second part of the CryoVEx 2011 campaign covered the Greenland ice sheet (EGIG line), the local ice caps (Austfonna and Devon), and sea ice flights around research vessel RV Lance in Fram Strait. Part of the EGIG line (T1-T15) was flown multiple times. At the first overflights (April 26 and 27), no scientists were on the ground due to extreme cold temperatures on the ice sheet, preventing any work. However, on May 9, a corner reflector was put up at T15, which were overflown in different heights to obtain ASIRAS data in both low and high altitude mode. Austfonna and RV Lance flights were both flown on April 30 out of Longyearbyen, Svalbard. The weather on Austfonna was excellent and the full program covering six validation lines and multiple corner reflectors were carried out. Precision of the validation line around RV Lance was hampered by a large drift of the sea ice in the area. The corner reflector closest to RV Lance was obtained visually by direct guidance of the ground team. On the route to RV Lance ASIRAS and ALS data were collected along CryoSat track 5599 from April 29. A few days of poor weather on the west coast (May 3-5) delayed the transit flight from Station Nord to Qaanaaq. The time was spent by surveying the sea ice in the Fram Strait for the Bureau of Mineral and Petrol. Finally, Devon ice cap was flown on May 7 in excellent weather conditions. The weather in Qaanaaq was marginal and put constraints on the time spend on the ice cap, thus only four lines of highest priority were measured.

The DTU Space part of the CryoVEx campaign ended on May 9. The team was stand by in Ilulissat until mid-day on May 12, in order to finalize flight lines for the BMP in Baffin Bay, however, low clouds and fog, caused by a stationary low pressure system, persistently covered the Baffin Bay, and the campaign had to be closed, as the extended charter period ended.

The cooperation between the ground and airborne teams was excellent, and contact by iridium phone with the ground teams prior to flights have been invaluable to receive update on weather conditions and positions of corner reflectors. A day-to-day overview is given in Section 2.2 and a more detailed description of the operations of the validation sites with examples, are given in Section 2.7.

Overall, the airborne campaign has been a success. A total of about 100 flight hours were flown covering about 23 500 km. The flight tracks including non-ESA flights are shown in Figure 1 and a list of the flights are shown in Table 1. Operator logs and plots of flight tracks are provided in Appendix 1. Overflights of corner reflectors demand very precise navigation as the reflector has to be within 10 m of the aircraft track, due to the narrow footprint of ASIRAS. By the aid of the onboard navigation system and the highly-skilled air crew only a few corner reflectors were missed out of a total of about 45 passes. The CryoVEx team now has a collection of unique measurements to analyze.

The airborne field team consisted of Henriette Skourup (HSK), Indriði Einarsson (IE), and Louise Sandberg Sørensen (SLSS) with assistance of Harald Lentz (HL) and Wolfram Borisch (WB) from Radar System Technique (RST) during the installation of the ASIRAS radar. Steen Savstrup Kristensen (SSK) and Anders Kusk (AK) participated during the PROMICE/POLARIS test flights.

2.2 Day to day

April 9-11	Installation and test flight Kangerlussuaq
April 12-13	Transit flight Kangerlussuaq-Alert with test of ASIRAS on the route.
April 14	Flight to survey *in situ* site North (NICE)
April 15	Coincident flight with Polar-5 (AEM) of CryoSat track 5399 followed by survey of *in situ* site South (SICE)
April 16	Overflight of *in situ* site South (SICE) with ALS, flight in the Lincoln Sea to repeat previous survey lines (2006, 2008) and overflight of survey site on fast ice (FICE) outside Alert.
April 17	Coincident flight with Polar-5 (AEM) of CryoSat track 5428, followed by calibration flight of Spinnaker building, runway and FICE
April 18	No flights, waiting for ground team to finish measurements with GPR
April 19	Flight Alert to Kangerlussuaq, no survey on the way due to poor visibility. Local flight in the fjord outside Qaanaaq for Greenland Climate Research Center and survey over the Baffin Bay on the route (BMP)
April 20-25	PROMICE and test flight of ESA radar POLARIS.
April 26	Flight Kangerlussuaq to Ilulissat. Calibration flight over storage building in Kangerlussuaq, CryoSat track 5363 over the Greenland ice sheet, and EGIG line T12-T1 on route Ilulissat.
April 27	Ilulissat to Danmarkshavn. Skipped refuelling in Constable Pynt due to poor weather. No surveying between EGIG line WP EG6 and the marginal ice sheet between 74.4-76.9^{o}N on the East coast due to poor weather.
April 28	Danmarkshavn to Station Nord. Had to cancel the sea ice flight in Fram Strait for Bureau of Mineral and Petrol due to very low clouds/fog in the area. On the flight from Station Nord to Longyearbyen, Svalbard, the weather only permitted survey of a small part of the Fram Strait near the ice edge.
April 29	No flying due to poor weather
April 30	Austfonna and RV Lance flights. Followed CryoSat ground track 5599 from April 29, on the route to RV Lance.
May 1	No flying due to poor weather

May 2 Svalbard to Station Nord, no surveying due to low clouds in the area. Kongsvegen skipped due to clouds in the area. A sea ice flight north of Station Nord (triangle) and calibration of building Station Nord were flown subsequently. Patches of fog were observed in the easternmost area.

May 3 Two sea ice flights in Fram Strait to cover the tracks for Bureau of Minerals and Petrol

May 4-5 No flying due to poor weather

May 6 Station Nord to Qaanaaq

May 7 Devon ice cap

May 8 Flight Qaanaaq to Ilulissat. Northernmost track (K10-K9) for Bureau of Mineral and Petrol flown. The southernmost lines were covered in fog. ESA press in Ilulissat.

May 9 EGIG line to overfly corner reflector placed at T15

May 10-12 No flying due to low clouds and fog, caused by a stationary low pressure system in the Baffin Bay

May 12 No clearing in the weather – Cancel the last flight for BMP. Flight Ilulissat to Kangerlussuaq.

May 13 Transfer flight science team Kangerlussuaq to Akureyri

Figure 2: Heavy sea ice conditions outside CFS Alert (left) and terminal of Austfonna ice cap (right)

Table 1: Overview of CryoVEx 2011 flights.The flights at the CryoVEx validation sites are highlighted by blue

Date	DOY	Flight	Track	Take off UTC	Landing UTC	Airborne	Airborne accumulated	Survey operator
10-04-2011	100		SFJ testflight	20:03	20:34	31 m	31 m	IE/HSK
12-04-2011	102	a	SFJ-JUV	11:30	14:01	2 hrs 31 m	3 hrs 2 m	No survey
12-04-2011	102	b	JUV-NAQ	14:35	17:21	2 hrs 46 m	5 hrs 48 m	IE/HSK
13-04-2011	103		NAQ-YLT	15:38	18:03	2 hrs 25 m	8 hrs 13 m	No survey
14-04-2011	104		YLT-NICE-YLT	16:55	21:00	4 hrs 05 m	12 hrs 18 m	IE/HSK
15-04-2011	105	a	YLT-CRYOSAT-YLT	15:02	18:39	3 hrs 37 m	15 hrs 55 m	IE/HSK
15-04-2011	105	b	YLT-SICE-YLT	19:45	21:50	2 hrs 5 m	18 hrs	IE/HSK
16-04-2011	106		YLT-D-S-FICE-YLT	14:11	18:35	4 hrs 24 m	22 hrs 24 m	IE/HSK
17-04-2011	107	a	YLT-CRYOSAT-YLT	13:53	17:41	3 hrs 48 m	26 hrs 12 m	IE/HSK
17-04-2011	107	b	YLT-CALIB-FICE-YLT	19:16	19:54	38 m	26 hrs 50 m	IE/HSK
19-04-2011	109	a	YLT-NAQ	12:56	15:18	2 hrs 22 m	29 hrs 12 m	IE/HSK
19-04-2011	109	b	NAQ-SFJ	16:07	21:27	4 hrs 20 m	33 hrs 32 m	IE/HSK
22-04-2011	112	a	SFJ-PROMICE-GCRC-	12:03	16:19	4 hrs 16 m	37 hrs 48 m	HSK
22-04-2011	112	b	UAK-ESA POLARIS-	17:33	20:56	3 hrs 23 m	41 hrs 11 m	HSK
26-04-2011	116		SFJ-CAL-CRYOSAT-T12-T1-JAV	12:34	16:57	4 hrs 23 m	45 hrs 33 m	SLSS/HSK
27-04-2011	117		JAV-EGIG-B-DMH	11:08	17:30	6 hrs 22 m	51 hrs 55 m	SLSS/HSK
28-04-2011	118	a	DMH-RD-NRD	09:22	12:29	3 hrs 07 m	55 hrs 02 m	SLSS/HSK
28-04-2011	118	b	NRD-LYR	13:56	16:37	2 hrs 41 m	57 hrs 43 m	SLSS/HSK
30-04-2011	120	a	LYR-AUSTFONNA-	06:20	11:01	4 hrs 41 m	62 hrs 24 m	SLSS/HSK
30-04-2011	120	b	LYR-RVLANCE-LYR	12:05	15:50	3 hrs 45 m	66 hrs 09 m	SLSS/HSK
02-05-2011	122	a	LYR-NRD	08:23	11:16	2 hrs 53 m	69 hrs 02 m	No survey
02-05-2011	122	b	NRD-F-CAL-NRD	13:58	19:12	5 hrs 14 m	74 hrs 16 m	IE/HSK
03-05-2011	123	a	NRD-RD-NRD	11:46	17:09	5 hrs 23 m	79 hrs 39 m	IE/HSK
03-05-2011	123	b	NRD-RD-NRD	17:33	20:42	3 hrs 09 m	82 hrs 48 m	IE/HSK
06-05-2011	126		NRD-H-A-NAQ	10:49	15:44	4 hrs 55 m	87 hrs 43 m	IE/HSK
07-05-2011	127		NAQ-DEVON-NAQ	15:55	21:02	5 hrs 07 m	92 hrs 50 m	IE/HSK
08-05-2011	128		NAQ-RD-JAV	13:45	19:22	5 hrs 37 m	98 hrs 27 m	IE/HSK
09-05-2011	129		JAV-EGIG-JAV	12:08	14:46	2 hrs 38 m	101 hrs 05 m	IE/HSK
12-05-2011	132		JAV-SFJ	15:09	16:22	1 hrs 13 m	102 hrs 18 m	No survey
13-05-2011	133		SFJ-AEY					No survey
TOTAL							**102 hrs 18 m**	

2.3 Hardware installation

The upgraded ASIRAS system primarily included a new PC system. As the new PC system fitted into the same rack and were of lighter weight, compared to the old PC system, the same certification and setup could be used for the Twin Otter (TF-POF) as in CryoVEx campaigns 2006 and 2008 (Stenseng et al (2007) and Hvidegaard et al (2009)). To support the upgraded ASIRAS system a Novatel GPS DL-V3 was kindly loaned from the Alfred Wegener Institute (AWI).

The primary ALS equipment used is the Riegl LMS Q-240i (also used in CryoVEx 2008). A backup unit Riegl LMS Q-140i, was used during the first part of the CryoVEx 2011 campaign (April 9-25). This was the same as used through previous CryoVEx campaigns (2006, 2004 and 2003).

Other ancillary equipment to be mounted includes precise dual-frequency GPS receivers for precise aircraft positioning. Several receivers are mounted and connected to two separate GPS antennas ("front" and "rear") through antenna beam splitters. The GPS antennas are permanently installed on TF-POF. The GPS units used here are a Javad Delta (AIR1 and AIR3) and a Javad Lexon (AIR2). Both AIR1 and AIR3 were connected to the front antenna, whereas AIR2 was connected to the rear antenna. Typical logging rates of 1 Hz were used, except for AIR2, which logged data with 2 Hz to obtain a higher precision for the on-board navigation system. Offsets between GPS antennas and ASIRAS/ALS are given in Table 2.

To record the attitude (pitch, roll and heading) of the aircraft, two inertial navigation systems (INS) are used. The primary unit is a medium grade INS of type Honeywell H-764G. This unit collects data both in a free-inertial and a GPS-aided mode at 50 Hz. Specified accuracy levels in roll and pitch are better than 0.1^{o}, and usual accuracy is higher than this. A backup INS is provided by an OXTS Inertial+2 integrated GPS-INS unit, with a nominal similar accuracy as the H-764G.

A nadir looking webcam, of type uEYE UI-2240RE-C with KOWA LM4NCL 3.5 mm lense, collects nadir-looking imagery with resolution 1280x1024 every second triggered by PPS from a Javad receiver. This is supplemented by slant-looking images and video on occasional basis.

The setup of the instruments in the aircraft is shown in Figure 3 and pictures of the various instruments are shown in Figure 4.

Table 2: The dx, dy and dz offsets for the lever arm form the GPS antennas to the origin of the laser scanner, and to the back centre of the ASIRAS antenna (see arrow Figure 3)

To laser scanner	**dx (m)**	**dy (m)**	**Dz (m)**
from AIR1/AIR3 (front)	- 3.70	+ 0.52	+ 1.58
from AIR2/AIR4 (rear)	+ 0.00	- 0.35	+ 1.42
to ASIRAS antenna	**dx (m)**	**dy (m)**	**dz (m)**
from AIR1/AIR3 (front)	-3.37	+0.47	+2.005
from AIR2/AIR4 (rear)	+0.33	-0.40	+1.845

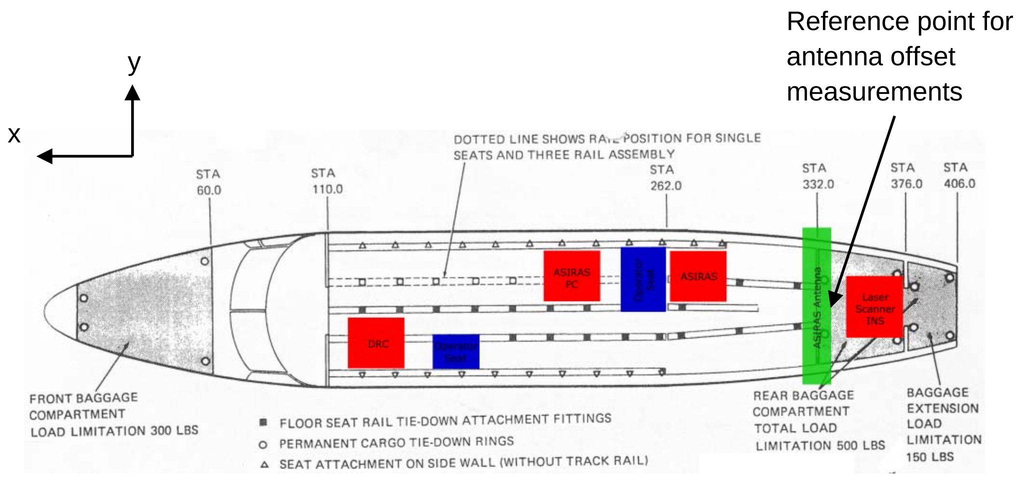
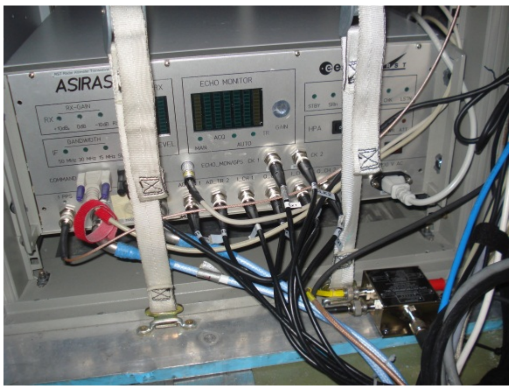


Figure 3: Overall layout of hardware in the TF-POF Twin Otter aircraft

(a) ALS (Q-140i) packed with foam and external 110V heaters, H-764G INS (grey box in the back) and OXTS INS (red box)

(b) Front rack with integrated power unit, solid state discs and GPS receivers

(c) ASIRAS antenna



(d) Rear rack with ASIRAS system

Figure 4 (a-c): Pictures of the aircraft instrument setup

2.4 Overview of acquired data

Data aquisition of the various instruments were acquired where feasible, considering the limited height range of the ALS system and the large volume of ASIRAS data. An overview of all acquired data are listed in Table 3.

By far most of the ASIRAS data was acquired in Low Altitude Mode (LAM) with low along-track resolution (LAMa). This allows flight at an altitude of 300 m, which is within the operational range of the ALS system and a relative low data volume of about 28 GB per hour. On request the mode was switched to either high resolution LAM or High Altitude Mode (HAM) at two occations. Data acquired in high resolution LAM, increases the along-track resolution and thus the data volume increases to 110 GB per hour. To acquire ASIRAS data in HAM, the flight altitude has to be above 1 200 m, excluding the option for coincident ALS data acquisition. The HAM data volume are relative low with only 8 GB per hour. A total 1.4 TB raw ASIRAS data were collected during the CryoVEx 2011 campaign. The data was stored on hard discs as ASIRAS level 0 raw data in the modified compressed format (Cullen, 2010).

In general the ALS worked excellent. As described in Section 2.1, the extreme cold conditions in Alert caused failure of the spare ALS (Q-140i) on several occations, see Table 3. However, data have been acquired at key sites with ground validation and for one long flight coordinated with P-3 and AEM observations. The data volume obtained by ALS is about 250-300 MB an hour which is a relative small amount, when compared to the ASIRAS data volume. During the campaign a total of 15.3 GB ALS data were acquired.

The airborne GPS units logged data internal in the receivers (AIR1, AIR2 and AIR3) during flights, which were downloaded upon landing on laptop PCs. The Novatel GPS was dedicated to support ASIRAS and was not part of the logging system. All GPS files were recovered and none of the receivers failed during flight. The GPS reference stations listed in Table 3 are described in further detail in Sections 2.5.1.

At a few flights (DOY 104, 105b, and 122b) the inertial navigation system H-764G INS stopped logging in the air, causing loss of data. On one occation (DOY 108) the external power bottun was accidentially activated and the system turned off during flight. The data from DOY 105a, 107a, and 107b have not been initialised properly at the alignment but this will not affect the laser scanner processing as the files still contains the information needed about attitude changes. In general the OXTS INS worked fine, but lost GPS signal during flight at several occations, this only affects the internal GPS solution, and will not affect the results as the final processing will rely on the external GPS receivers. Due to the backup system, INS data from all flights have been obtained.

To support the analysis of ASIRAS and ALS, vertical photography was collected during flights. Pictures were acquired every second for most flights. Data were not acquired on the EGIG line, as there are no reference structures on the ice sheet, nor on Devon ice cap, where the contrast were overexposed. As supplement, a camcorder was installed during the flights for the Bureau of Mineral and Petrol.

All data are stored on external hard discs, as well as the DTU Space servers with tape backup system.

Table 3: Overview of data

Date	DOY	AIR1	AIR2	AIR3	INS OxTS	EGI	ALS	ASIRAS	GPS REF1	GPS REF2	WEB CAM	CAM COR-DER	LOG	REMARKS
10-04-2011	100	X	X	X	X	X		LAMa		SFJ2	X		X	TEST FLIGHT, SFJ
14-04-2011	104	X	X	X	X	X[1)]		LAMa	YLT1	YLT2	X		X	Alert NICE
15-04-2011	105a	X	X	X	X	X	X[4)]	LAMa	YLT1	YLT2	X		X	Alert CryoSat (Polar-5)
15-04-2011	105b	X	X	X	X	X[1+2)]		LAMa/LAM	YLT1	YLT2	X		X	Alert SICE
16-04-2011	106	X	X	X	X[3)]	X	X[5)]	LAMa	YLT1	YLT2	X		X	Alert Triangle + FICE
17-04-2011	107a	X	X	X	X	X[2)]		LAMa	YLT1	YLT2	X		X	Alert CryoSat (Polar-5)
17-04-2011	107b	X	X	X	X	X[2)]	X	LAMa	YLT1	YLT2	X		X	Alert CAL + FICE
19-04-2011	109a	X	X	X	X[3)]	X	X	LAMa			X		X	Only a bit of Nares St
19-04-2011	109b	X	X	X	X[3)]	X	X	LAMa			X		X	GCRC (Qaanaaq), BMP
22-04-2011	112a	X	X	X	X	X[11)]	X		SFJ1	SFJ2	X[6)]		X	PROMICE, GCRC
22-04-2011	112b	X	X	X	X	X[11)]	X		SFJ1	SFJ2			X	PROMICE, POLARIS
26-04-2011	116	X	X	X	X[3)]	X	X	LAMa					X	CryoSat, EGIG
27-04-2011	117	X	X	X	X[7)]	X	X	LAMa					X	EGIG
28-04-2011	118a	X	X	X	X[3)]	X	X	LAMa			X	X	X	BMP
28-04-2011	118b	X	X	X	X	X	X	LAMa			X	X	X	No survey
30-04-2011	120a	X	X	X	X[3)]	X	X	LAMa	LYR1	LYR2	X		X	Austfonna
30-04-2011	120b	X	X	X	X	X	X	LAMa	LYR1	LYR2	X		X	RV Lance
02-05-2011	122b	X	X	X	X	X[1)]	X	LAMa	NRD1	NRD2	X		X	Triangle north of NRD
03-05-2011	123a	X	X	X	X	X	X	LAMa	NRD1	NRD2	X	X	X	BMP
03-05-2011	123b	X	X	X	X	X	X	LAMa	NRD1	NRD2	X	X	X	BMP
06-05-2011	126	X	X	X	X[8)]	X	X	LAMa					X	NRD-NAQ
07-05-2011	127	X	X	X	X[9)]	X	X	LAMa	NAQ1	NAQ2			X	Devon
08-05-2011	128	X	X	X	X	X[10)]	X	LAMa			X	X	X	BMP
09-05-2011	129	X	X	X	X[3)]	X	X	LAMa/HAM	JAV1	JAV2[12)]			X	EGIG

1) Logging thread stopped during flight
2) Not aligned
3) INS lost GPS signal during flight
4) Only first 45 minutes
5) No scanner last hour
6) Only for the GCRC flight at the KNS glacier
7) INS OxTS program froze, new INS file in the air
8) Data from 105900 (10 minutes into the flight, due to loose cable connection)
9) GPS signal lost at first transect at Devon icecap (CryoSat track May 1)
10) Green button at the EGI stopped by accident during flight
11) DTU Space north format, Anders Kusk
12) Stopped before landing

2.5 Processing

The data processing is divided between DTU Space and AWI. ASIRAS data is processed by AWI using GPS and INS data supplied by DTU Space. ASIRAS processor version ASIRAS_04_03 was used. GPS differential positioning, combined INS-GPS integration is done by DTU Space followed by processing of laser distance measurement into elevation above a reference ellipsoid. This is supplemented by georeference of the nadir photography.

2.5.1 GPS data processing

The exact position of the aircraft is found from the processed GPS data. Solutions have been obtained by use of both kinematic differential (DIF) processing and precise point positioning (PPP). Whereas the first method uses information from base stations in the processing procedure, the PPP method is only based on precise information of satellite clock and orbit errors.

The GPS base stations used as reference stations for differential post processing of the GPS data are listed in Table 4. The stations were mounted on roofs or tripods in the field near the landing sites; the reference points were generally not marked. Examples of GPS base stations at Station Nord and Qaanaaq airport are shown in Figure 5. In addition, data from permanent GPS stations were used for data processing.

Table 4: Overview of CryoVEx 2011 GPS reference stations

Name	Location	Antenna
SFJ2	Kangerlussuaq, Outside Air Greenland hangar, mounted on tripod on bench	MarAnt S/N 2170
SFJ 1	Kangerlussuaq, DMI hut, Mounted on stick on the roof of the DMI hut	RegAnt s/n 2349
YLT2	Alert, behind Hurricane building, Mounted on large DTU Space antenna tripod + rod (black short)	Internal antenna
YLT1	Alert, Apron, Mounted on small DTU Space antenna tripod	Novatel GPS-702-GG, P/N: 01017577
LYR1	Longyearbyen, Airport, Mounted on small DTU Space antenna tripod + rod (black short)	MarAnt S/N 2170
LYR2	Longyearbyen, Airport, Mounted on large DTU Space antenna tripod	Internal antenna
NRD1	Station Nord, Apron next to fuelpump	MarAnt S/N 2170
NRD2	Station Nord, Apron Koldhallen, Mounted on large DTU Space antenna tripod	Internal antenna
NAQ1	Qaanaaq, Airport	MarAnt S/N 2170
NAQ2	Qaanaaq, Airport apron, Mounted on large DTU Space antenna tripod	Internal antenna
JAV1	Ilulissat, Airport	MarAnt S/N 2170
JAV2	Ilulissat, Airport, Mounted on large DTU Space antenna tripod	Internal antenna

The position of the reference stations listed in Table 4, are determined using two of the available online GPS processing services AUSPOS (http://www.ga.gov.au/earth-monitoring/geodesy/auspos-online-gps-processing-service.html) and SCOUT (Scripps Coordinate Update Tool) service operated by SOPAC (Scripps Orbit and Permanent Array Center) (http://sopac.ucsd.edu). These services calculates the positions of the reference stations in ITRF 2005 reference system using data from the three nearest permanent GPS stations with a position accuracy of about 2 cm, even in the Arctic with long distance to permanent stations. The coordinates of all the reference stations used during CryoVEx 2011 are found in Appendix 2.

The GPS processing were performed with Waypoint GrafNav (version 8.20) by use of precise IGS orbit and clock files and correcting for ionospheric and tropospheric errors. For each flight, several solutions are made using different combinations of GPS reference stations and aircraft receivers. The best solution for each flight is selected according to Table 5 and used in the further processing.

Figure 5: GPS reference stations at Station Nord near the Apron (left) and Qaanaaq airport (right)

2.5.2 Inertial Navigation System

The position and attitude information (pitch, roll and heading) recovered from raw Honeywell (H-764G) and Oxford Inertial 2+ (OxTS) INS data at 10 Hz, are merged with the GPS solutions by draping the INS derived positions onto the GPS positions. The draping is done by modelling the function, found in the equation below, by a low pass smoothed correction curve, which is added to the INS.

$$\varepsilon(t) = P_{GPS}(t) - P_{INS}(t)$$

This way a smooth GPS-INS solution is obtained, which can be used for geolocation of laser and webcam observations.

The H-764G INS data turned out to have many small gaps of 2-4 sec duration, caused by a slow data logging system. The solid state discs were simply too slow to log INS data in parallel with data acquisition of webcam. Installation and test of an updated solid state disc for data logging has removed the data logging issues. The software was updated to handle timeshifts of the data, caused by gaps larger than 1 second.

The backup INS unit OxTS performs excellent over long straight sections at fixed altitude. However, the OxTS INS has degraded accuracy during accelerations, which includes turns and rapid changes of altitude. This hampers calibration of the instrument, as overflights of buildings and cross-overs usually involves lots of turns, see Section 2.5.3.

Combined GPS-OxTS solutions have been used primarily for long straight flights, such as most sea ice flights and Austfonna ice cap. Elsewhere the solutions are based on Honeywell data. Where many large gaps occurs (e.g. Devon ice cap) the problems have been overcome by merging OxTS data to the H-764G data to obtain better quality. The selected INS solution is listed in Table 5.

The best solutions of both GPS and INS data based on Table 5 are packed as binary files in the special ESA file format, see Appendix 4.2 and 4.3. An overview of the final GPS and INS files are listed in Appendix 5 and 6, respectively, with file name convention according to Appendix 3.

Table 5: List of best combination of GPS and INS data

Date	DOY	File name	Reference	Processing	INS	Rover
14-04-2011	104	104_a2.pos	YLT1/YLT2	DIF	H-764G	AIR2
15-04-2011	105a	105A_comb.pos	YLT1/YLT2	DIF	H-764G	AIR1/3
15-04-2011	105b	105B_a2j.pos	YLT1/YLT2	DIF	OxTS	AIR2
16-04-2011	106	106_a2.pos	YLT1/YLT2	DIF	OxTS	AIR2
17-04-2011	107a	107A_a2j.pos	YLT2	DIF	OxTS	AIR2
17-04-2011	107b	107B_a2.pos	YLT2	DIF	H-764G	AIR2
19-04-2011	109a	109A_a2.pos	KMOR*	DIF	H-764G/OxTS	AIR2
19-04-2011	109b	109B_a2_ppp.pos	None	PPP	H-764G/OxTS	AIR2
22-04-2011	112a	112A_a2.pos	SFJ1/SFJ2	DIF	H-764G	AIR2
22-04-2011	112b	112B_a2_comb.pos	SFJ1/SFJ2/NNVN	DIF	H-764G	AIR2
26-04-2011	116	116_a2.pos	Kaga1160*/kely1	DIF	H-764G	AIR2
27-04-2011	117	117_a2_ppp.pos	None	PPP	H-764G	AIR2
28-04-2011	118a	118A_a2_ppp.pos	None	PPP	OxTS	AIR2
28-04-2011	118b	118B_a2_ppp.pos	None	PPP	No survey	AIR2
30-04-2011	120a	120A_a2_kar.pos	LYR1/LYR2	DIF	OxTS	AIR2
30-04-2011	120b	120B_a2.pos	LYR1/LYR2	DIF	OxTS	AIR2
02-05-2011	122	122b_a2_fwd.pos	NRD1/NRD2	DIF	OxTS	AIR2
03-05-2011	123a	123A_a2.pos	NRD1/NRD2	DIF	OxTS	AIR2
03-05-2011	123b	123B_a3.pos	NRD1/NRD2	DIF	OxTS	AIR3
06-05-2011	126	126_a2_ppp.pos	None	PPP	OxTS	AIR2
07-05-2011	127	127_a2_comb.pos	NAQ1/NAQ2/TH	DIF	H-764/OxTS	AIR2
08-05-2011	128	128_a2_ppp.pos	None	PPP	OxTS	AIR2
09-05-2011	129	129_a2_ref.pos	KAGA*	DIF	OxTS	AIR2

*KMOR Washington land (UNAVCO), NNVN North of Niviarsiat Nuvatak (UNAVCO), KAGA Ilulissat (UNAVCO), KELY Kangerlussuaq (IGS,JPL), THU2 Thule AB (IGS,NSI)

2.5.3 Laser scanner data processing

The two laser scanners are almost identical measuring with a horizontal resolution of 0.7 m x 0.7 m at a flight height of 300 m and a ground speed of 250 kph. The across-track swath width is roughly equal to the flight height, and the vertical accuracy is in the order of 10 cm depending primarily on uncertainties in the kinematic GPS-solutions.

The same processing scheme as previous years have been used (Stenseng et al (2007) and Hvidegaard et al (2009)). Table 7 and 8 shows the raw logged files with start /stop times. The data rate has been fixed to 208 and 251 observations per line, for the LMS Q-140i and LMS Q-240i, respectively, both instruments record 40 lines per seconds.

Calibration of ALS misalignment angles between ALS and INS was estimated from successive overflights from different directions of the same building, where the position of the corners are known with high precision from GPS measurements. These calibration maneuvers have been carried out in Kangerslussuaq (DOY 116), CFS Alert (DOY 107) and Station Nord (DOY 122), see example from overflight of storage building in Kangerlussuaq in Figure 6.

The offsets angles for each flight are listed in Table 7 and 8. Based on the calibration flights the Honeywell (H-764G) INS have almost the same angular offsets as previous years. It has not been possible to obtain a consistent set of angular offsets based on the calibration flights for the OxTS INS caused by drift of the instrument during turns. In this case, roll and pitch angles have been determined over flat smooth sea ice surfaces, togehter with cross-overs. Heading offsets are estimated by comparing coincident data processed with OxTS and H-764G.

The processing of ALS (Q-240i) has been straightforward. The spare ALS (Q-140i) instrument lacked proper GPS datation on some flights, see notes in Table 7. For DOY 105 data cannot be recovered due to this problem. For DOY 107, flight B, the data have been manually fitted to corner reflector sites using the CR positions from GPS. The same procedure has been used for the runway using the positions of the calibration building in CFS Alert (Spinnaker). Full scans are missing in the data for Q-140i ALS on a regular basis (1 out of 10 to 1 out of 20 lines), as also seen in CryoVEx 2006 with the same instrument.

Reflections from thin clouds for flights 116, 117 and 126 have been removed by a simple filtering procedure. An example along a transect of the Greenland Ice Sheet (DOY 116) of ALS reflections before and after applying the “cloud” filter is given in Figure 7.

The ALS data is in general of high quality with a standard deviation of cross-overs of less than 5 cm, see Table 6, except at Devon ice cap and Alert sea ice. This is primarily due to the topography at Devon ice cap and due to a small drift of sea ice. No cross over analysis was made for RV Lance flight due to a large drift of the sea ice, see Section 2.7.5.

Processed data comes as geo-located point clouds, in lines of width 200-300 m at coarse resolution 5 x 5m and for special validation sites or by request in full resolution 1x1 m, in format time, latitude, longitude, heights given with respect to WGS-84 reference ellipsoid. The data is packed in binary data files in the special ESA format, see Appendix 4.4. An overview of the processed data is given in Appendix 7 and 8 with file names convention listed in Appendix 3.

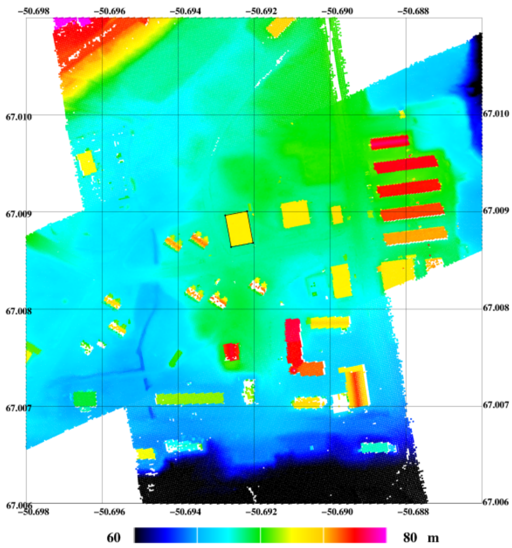



Figure 6: Storage building in Kangerlussuaq used for calibration of ALS (left) and ALS ellipsoid heights from calibration flight in Kangerlussuaq on April 26 (right)

Table 6: ALS cross-over statistics from validation sites

Date	DOY	Validation site	Mean (m)	Std.dev (m)	min (m)	max (m)
16-04-2011	106	Alert sea ice small drift	-0.14	0.34	-3.28	3.08
26-04-2011	116	EGIG line	-0.03	0.04	-0.17	0.15
			0.07	0.04	-0.07	0.21
27-04-2011	117	EGIG line	0.09	0.04	-0.07	0.29
			0.03	0.05	-0.14	0.20
09-05-2011	129	EGIG line	0.00	0.03	-0.12	0.12
			-0.05	0.04	-0.17	0.10
			-0.05	0.04	-0.17	0.11
30-04-2011	120A	Austfonna	0.00	0.01	-0.07	0.09
			-0.02	0.05	-0.24	0.20
			-0.02	0.05	-0.20	0.19
07-05-2011	127	Devon	-0.06	0.04	-0.23	0.15
			-0.08	0.06	-0.26	0.87
			-0.02	0.07	-0.24	0.93

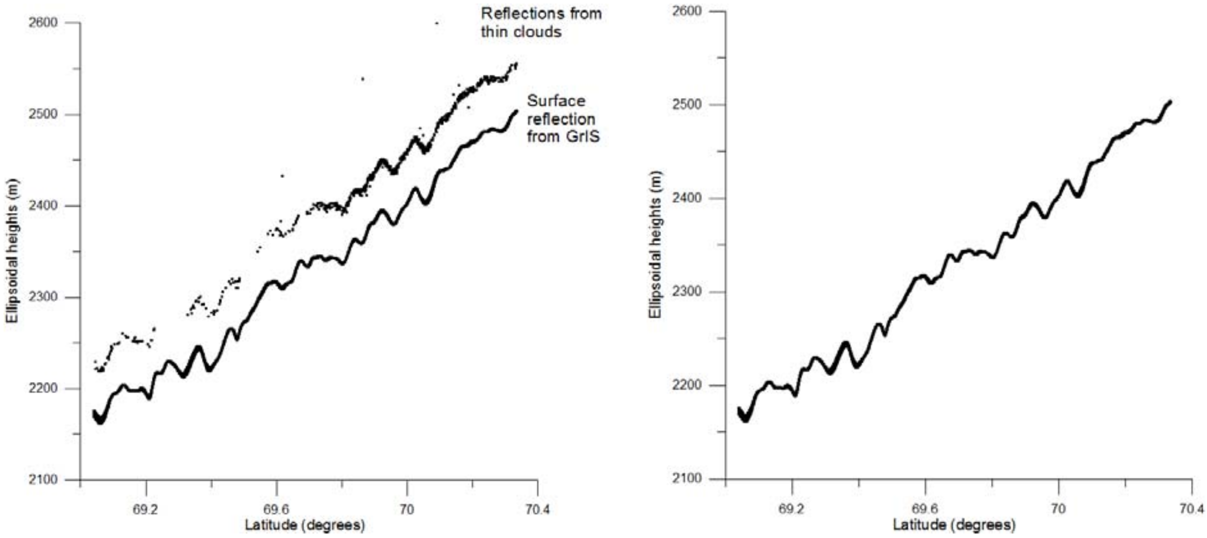


Figure 7: Ellipsoidal heights of ALS over the Greenland Ice Sheet (GrIS) day 116 before (left) and after (right) removing reflections from thin clouds

Table 7: Recorded ALS data Riegl LMS Q-140i

Date	DOY	ALS Raw file	Start (dechr)	Stop (dechr)	dt (s)	Angles
15-04-2011	105	105_150900.LOG	15.16604	15.18246	n/a	No timing from PPS
16-04-2011	106	106_140100.LOG	14.20216	14.96525	3	0.55 0.36 5.0
		106_150000.LOG	15.00008	16.00879	0	0.55 0.36 5.0
		106_160200.LOG	16.03341	17.01056	0	0.55 0.36 5.0
		106_170200.LOG	17.03340	17.55822	0	0.55 0.36 5.0
17-04-2011	107	107_184700.LOG	18.78333	n/a	n/a	.DEFAULT Sync sec not ok 0.3 0.20/0.46/0.34 0.7*
19-04-2011	109	109_131130.LOG	13.19175	13.46860	n/a	Nares Strait
		109_160400.LOG	16.12594	16.69235	0	Qaanaaq
		109_164300.LOG	16.71678	17.46711	0	GrIS
		109_172900.LOG	17.48342	18.48426	1	0.55 0.34 0.70
		109_173000.LOG	18.50012	19.06108	0	0.55 0.34 0.70
22-04-2011	112	112_115430.LOG	11.90833	n/a	n/a	Sync sec not ok
		112_122800.LOG	12.49818	12.48057	n/a	No timing from PPS
		112_133430.LOG	13.59639	13.60930	n/a	No timing from PPS
		112_140930.LOG	14.20382	14.19460	n/a	No timing from PPS
		112_150300.LOG	15.05518	15.07920	n/a	No timing from PPS
		112_173500.LOG	17.61954	17.62553	n/a	No timing from PPS
		112_174230.LOG	17.72105	17.71077	n/a	No timing from PPS

*roll angles for Runway/FICE1/FICE2, local adjustment due to failure of scanner timing

Table 8: Recorded ALS data Riegl LMS Q-240i

Date	DOY	ALS Raw file	Start (dechr)	Stop (dechr)	dt (s)	Angles
26-04-2011	116	116_123630.2dd	12.60876	12.72661	-1	-1.60 0.2 0.0
		116_124630.2dd	12.77537	13.20539	-1	-1.60 0.2 0.0
		116_131300.2dd	13.21704	14.13042	-1	-1.60 0.2 0.0
		116_140900.2dd	14.15039	15.06142	-1	-1.60 0.2 0.0
		116_150430.2dd	15.07536	15.68049	-1	-1.60 0.2 0.0
		116_154130.2dd	15.69207	16.77757	-1	-1.60 0.2 0.0
27-04-2011	117	117_111130.2dd	11.19201	11.97399	-1	-1.60 0.2 0.0
		117_120000.2dd	12.00035	12.97650	-1	-1.60 0.2 0.0
		117_130000.2dd	13.00036	14.08845	-1	-1.60 0.2 0.0
		117_154530.2dd	15.75875	16.96705	-1	-1.60 0.2 0.0
28-04-2011	118	118_092515.2dd	09.42126	10.11894	-1	-1.75 -0.12 0.0
		118_103430.2dd	10.57542	11.58337	-1	-1.75 -0.12 0.0
		118_145700.2dd	14.95041	15.45603		
30-04-2011	120	120_070800.2dd	07.13370	07.86901	-1	-1.75 0.01 0.0
		120_075300.2dd	07.88366	08.80537	-1	-1.75 0.01 0.0
		120_084900.2dd	08.81698	09.53602	-1	-1.75 0.01 0.0
		120_093300.2dd	09.55038	09.97130	-1	-1.75 0.01 0.0
		120_125330.2dd	12.89211	14.02605	-1	-1.75 0.03 -4.0
		120_140200.2dd	14.03338	14.52785	-1	-1.75 0.03 -4.0
02-05-2011	122	122_140100.2dd	14.01702	14.98350	-1	-1.75 0.01 0.0
		122_150000.2dd	15.00034	15.93254	-1	-1.75 0.01 0.0
		122_155630.2dd	15.94207	16.90388	-1	-1.75 0.01 0.0
		122_165500.2dd	16.91696	17.96904	-1	-1.75 0.01 0.0
		122_175830.2dd	17.97532	18.93486	-1	-1.75 0.01 0.0
		122_185700.2dd	18.95037	19.14708	-1	-1.75 0.01 0.0
03-05-2011	123	123_122000.2dd	12.33368	13.46869	-1	-1.75 0.01 0.0
		123_132900.2dd	13.48374	14.44338	-1	-1.75 0.01 0.0
		123_142800.2dd	14.46675	15.63327	-1	-1.75 0.01 0.0
		123_153830.2dd	15.64205	16.28849	-1	-1.75 0.01 0.0
		123_175000.2dd	17.83372	18.79538	-1	-1.75 0.01 0.0
		123_184930.2dd	18.82532	19.59779	-1	-1.75 0.01 0.0
06-05-2011	126	126_105530.2dd	10.92539	11.99398	-1	-1.75 -0.16 0.0
		126_120030.2dd	12.00873	13.00198	-1	-1.75 -0.16 0.0
		126_130100.2dd	13.01698	14.01756	-1	-1.75 -0.16 0.0
		126_140130.2dd	14.02537	15.01581	-1	-1.75 -0.16 0.0
		126_150130.2dd	15.02537	15.25125	-1	-1.75 -0.16 0.0
07-05-2011	127	127_173000.2dd	17.50037	18.04549	-1	-1.60 0.2 0.0
		127_180330.2dd	18.05873	18.61811	-1	-1.60 0.2 0.0
		127_183800.2dd	18.63372	19.01573	-1	-1.60 0.2 0.0
		127_190730.2dd	19.12535	19.41699	-1	-1.60 0.2 0.0
08-05-2011	128	128_143000.2dd	14.50032	15.47576	-1	-1.75 -0.16 0.0
		128_152930.2dd	15.49208	16.50114	-1	-1.75 -0.16 0.0
		128_163030.2dd	16.50871	16.65231	-1	-1.75 -0.16 0.0
09-05-2011	129	129_123800.2dd	12.63371	13.49968	-1	-1.675 0.23 0.0

2.6 ASIRAS data processing

The ASIRAS processing of the CryoVEx 2011 data is analogous to the concepts presented in Helm et al. (2006). The full data set was processed with ESA's processor version ASIRAS_04_03. A summary of the processing together with plots of every single profile is given in Appendix 9. A couple of tests were applied to address datation issues and to show the quality of the Level_1b product. In general the data shows no datation errors and in most cases good quality, however in some specific areas the re-tracked elevation shows reduced quality. Similar results were obtained and highlighted in former reports (e.g. Helm et. al, 2006; Stenseng et al. 2007) and therefore are not shown here again, since the implemented OCOG retracker has not changed. The OCOG was developed to give a quick and rough estimate of surface elevation and not to be as precise as possible. Therefore it is up to the user of the data to apply different re-tracker algorithms instead of the OCOG.

2.6.1 Runway overflights and comparison with ALS-DEM

Runway overflights were performed in Alert at 17th April. Figure 8 shows the laser scanner elevation model of the Alert runway including the ASIRAS profile (black line). Gaps in the line show areas where the roll angles are larger than 1.5°. This data was excluded from the analysis. ASIRAS profile A110417_01 was used to calibrate the system with the ALS-DEM. In Figure 9 the comparison is shown. The black line in the upper panel shows the ALS elevation, whereas the dark gray line shows the ASIRAS elevation. The light gray line shows the roll angle. A difference of 3.53m +/- 0.04m between both elevations is determined with the OCOG retracker. The lower left panel shows the variation of the difference around the median value. Statistics of this variation is shown in the histogram. Note that, this offset was not considered in the final ASIRAS level_1b processing, since it is dependent on the choice of retracker. Table 9 lists the runway overflight and the calibration result.

Table 9: Runway calibration

Profile	Start time	Stop time	Time shift (s)	Offset (m)	Stddev (m)	ALS qual.	ASIRAS qual.
A110417_01	69,905	69,935	0.00	3.53	0.04	Good	Good

2.6.2 Corner reflector overflights

Throughout the campaign there have been several overflights of the corner reflectors put out at the test sites. The positions of all corner reflectors can be found in Table 10. All CR-passes were analyzed and successful hits are listed in Table 11. It is seen that none of the CR placed on Austfonna were hit, whereas all CR's on the sea ice, along the EGIG line and on Devon were hit. Due to the large drift of the RV Lance validation site no positions of the CR's were available and thus it has not been possible to locate the CR passes in the data. An example of Level_1b processed ASIRAS data of the CR pass over the Devon validation site is shown in Figure 10. The CR was hit around 0.19 km (66048.76s) and appears after processing as point target roughly 1 m above the surface. A subsurface layer can also be identified roughly 1m beneath the surface in this profile section. Successful CR passes are used for datation issues, described in section 2.6.3.

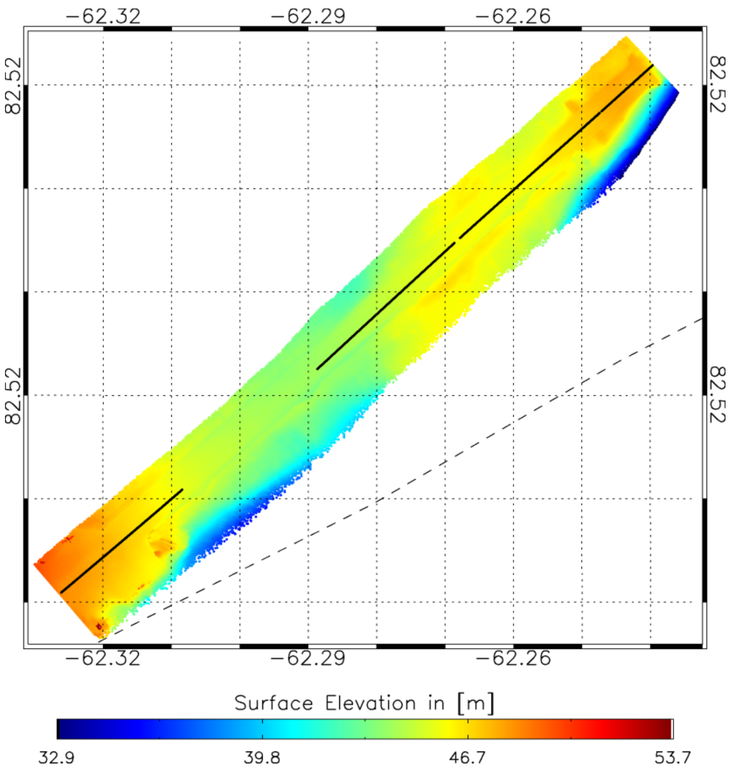


Figure 8: Laser scanner elevation model of runway in Alert

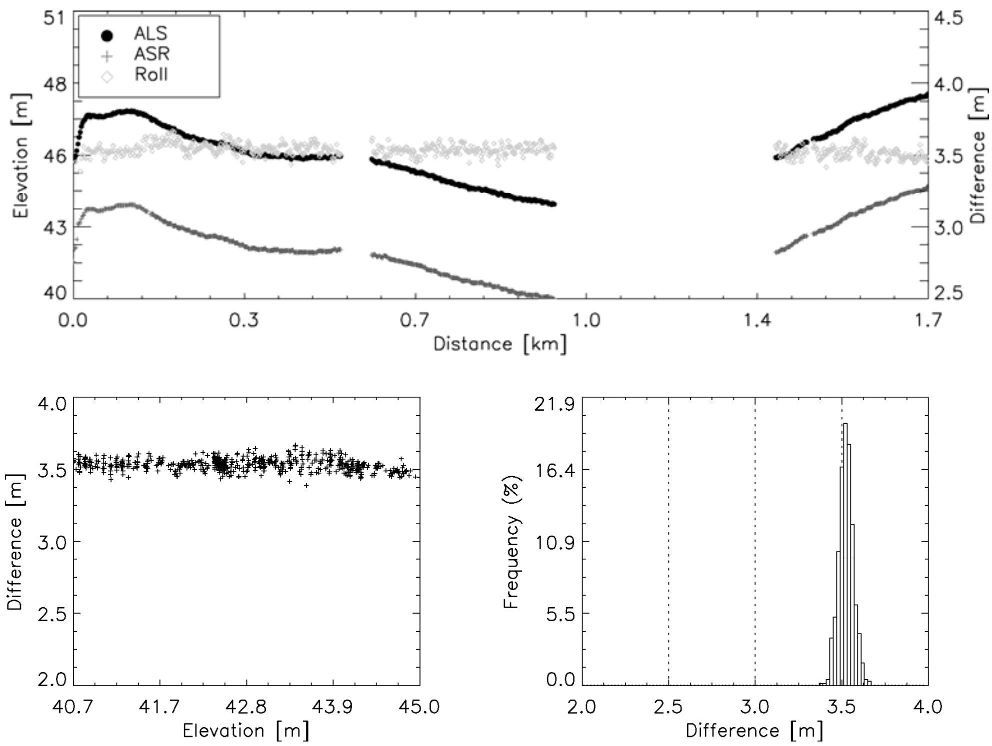


Figure 9: Comparison of ALS and ASIRAS elevations over runway. Top shows ALS elevation in black dots, ASIRAS elevation in dark grey dots and the light grey diamonds show the roll angle. Bottom shows variation of the difference and its statistics

Table 10: Position of corner reflectors installed in CryoVEx 2011

CR	Latitude	Longitude	Ground elevation (m)	Height (m)
11DEV1	75.338491	-82.67865	1796.846	0.93
11DEV2	75.382785	-82.705953	1791.652	1.13
11DEV3	75.338068	-82.677484	1796.559	1.2
11DEV4	75.338255	-82.677994	1796.7	1.14
11SICE1	83.61960	-62.872033	40.0	1.10
11SICE2	83.61800	-62.9080	40.0	1.10
11NICE1	85.58320	-69.63112	-	-
11NICE2	85.58220	-69.57568	-	-
11FICE1	82.5533611	-62.3564167	-	-
11FICE2	82.5490278	-62.3769167	-	-
11EGIG	70. 302472	-44. 754944	2643	1.175
11AUST1	79.769466	24.033579	754.6863	1.43
11AUST2	79.942547	24.243299	686.3973	1.41
11AUST3	79.829663	23.960178	817.9652	1.47
11AUST4	79.783975	23.143948	670.8911	1.44
11AUST5	79.745916	22.571393	422.683	1.54

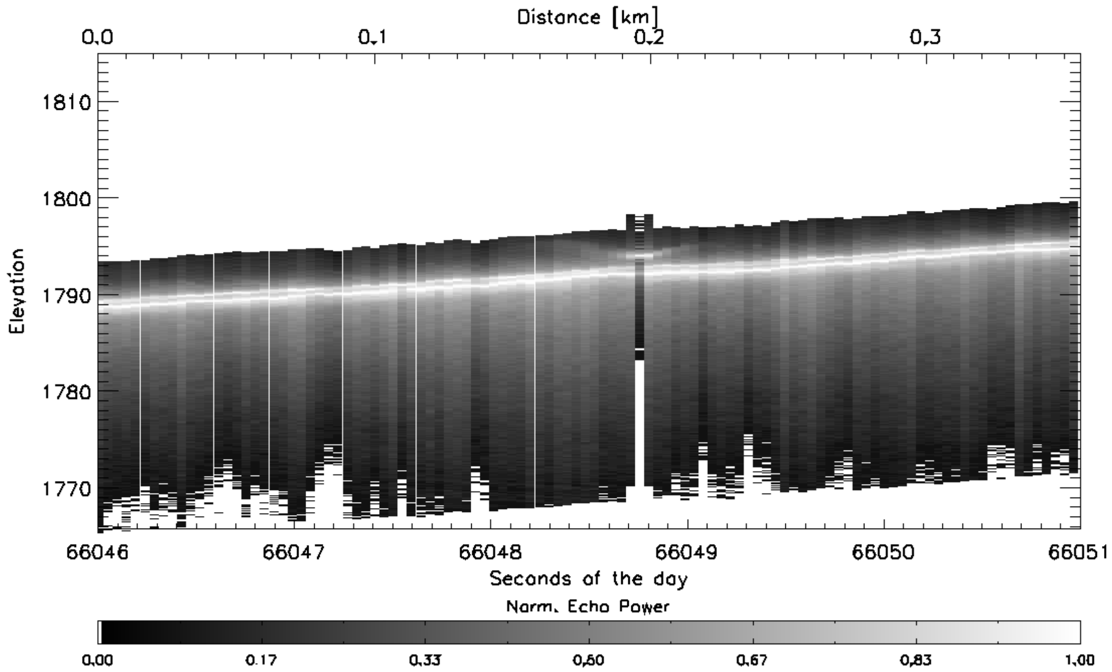


Figure 10: Successful CR pass over the validation site on the Devon icecap after ASIRAS processing. The CR is seen as point target roughly 1 m above the surface.

Table 11: Successful CR passes

CR	Profile	Closest approach (m)	Time (s)	Time shift (s)
11EGIG	A110509_01	3.51	47642.13	0.02
11EGIG	A110509_01	0.99	48548.34	0.02
11EGIG	A110509_02	3.75	49288.20	-0.05
11SICE2	A110415_01	7.17	75086.94	0.16
11SICE2	A110415_01	7.31	75592.69	-0.15
11SICE1	A110415_01	2.38	75094.61	-0.07
11CRFICE1	A110416_00	7.76	64768.15	0.00
11CRFICE1	A110416_00	13.04	66083.26	0.00
11CRFICE1	A110416_00	0.63	66578.46	0.00
11CRFICE2	A110416_00	5.61	64759.67	0.02
11CRFICE2	A110416_00	6.76	66569.75	0.02
11CRNICE1	A110414_00	2.62	69446.03	-0.05
11CRNICE1	A110414_00	0.43	66388.25	0.09
11CRNICE1	A110414_00	13.89	68529.94	-0.04
11CRNICE2	A110414_00	2.74	69976.08	0.12
11DEV1	A110507_01	9.57	63822.00	-0.02
11DEV2	A110507_01	2.82	63750.43	-0.03
11DEV3	A110507_01	4.56	67769.50	-0.01
11DEV4	A110507_01	5.12	63822.41	-0.02
11DEV4	A110507_01	1.11	66048.76	0.02

2.6.3 Datation tests

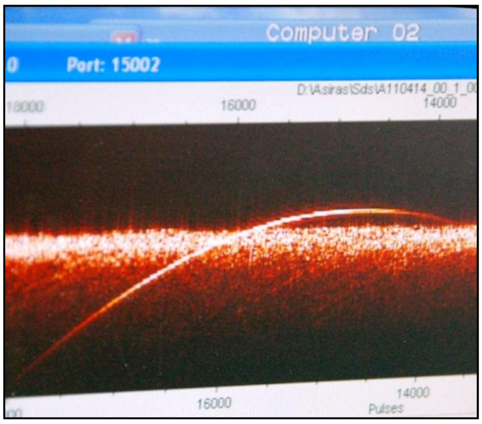
To investigate the datation issue only the CR test could be accomplished, since no laser scanner data were available at the time of ASIRAS processing. The CR test uses ground positions of the corner reflector and compares them to the position derived from the analysis of raw ASIRAS echoes. Here we found small time shifts that vary between -0.15 s and 0.16 s, see Table 11.

For the CRs along the EGIG line and on Devon the determined time shifts are around 0.03 s reflecting a positioning inaccuracy of max. 2 m. Some of the sea ice CR sites show larger offsets. For example the CR site 11SICE2 shows time offsets of -0.15 s and 0.16 s. The reason for those large time shifts can be positioning inaccuracy of the CR positions measured with handheld GPS and/or drift of the sea ice between ground measurement and overpass or an instrument datation issue. Since the two passes were flown from the opposite direction and the cumulative time shift of both passes result to 0.01 s we can conclude that the time shift is due to inaccurate CR position or sea ice drift, and not an instrument timing issue.

In summary, we conclude that level_1B data measured with the upgraded ASIRAS instrument and processed with the ASIRAS processor version ASIRAS_04_03 shows no time shifts and an overall good quality.

2.7 CryoVEx validation sites

Corner reflectors (CR) were placed by the ground teams at each validation site acting as a reference point for the radar signal. An overview of the position is given in Table 10. To overfly the corner reflectors demands very precise navigation as the reflector has to be within ±5 m of the aircraft ground track. The upgraded system of the ASIRAS radar has a real-time display, thus it is possible to see whether the reflector is hit on the overflight, see Figure 11. The attainment of correct flight lines is secured by a DTU Space in-house developed real-time software, which both allows pilot and scientists to monitor the flight locations in real time, relative to a planned track. It is routinely possible to obtain a nominal track accuracy at the 10 m level with this equipment, thus giving the necessary navigation accuracy for hitting ASIRAS corner reflectors on the ground. A particular high rate of corner reflectors was hit with very high precision in the CryoVEx 2011 campaign, see Section 2.6.2, thanks to the highly-skilled air crew.



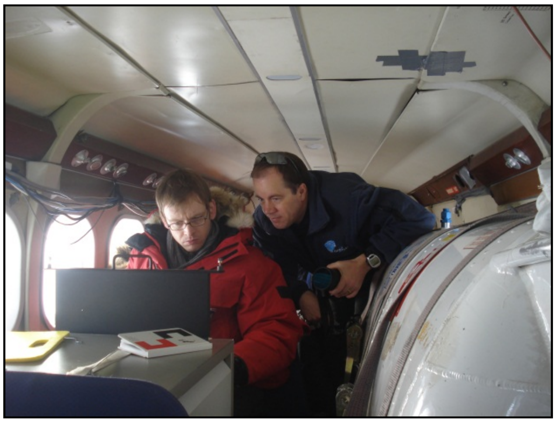


Figure 11: ASIRAS real-time display with the characteristic signal from a corner reflector (left) and operation of the ASIRAS (right) Credits: H. Skourup

2.7.1 Alert sea ice

In situ validation sites

Three validation sites had carefully been chosen by the ground team, two of them on the drifting sea ice to be under CryoSat-2 tracks, and the last on the fast ice just outside Alert. The northern most site (NICE) was established at approximately 85.6^{o}N 62.9^{o}W, the southern site (SICE) 83.6^{o}N 69.6^{o}W and the fast ice site (FICE) 82.5^{o}N 62.4^{o}W, see red circles in Figure 13. The ground team erected 2 corner reflectors approximately 500 m apart on each validation sites. The corner reflectors were marked by tarps, which were clearly visible in webcam pictures, see Figure 12, obtained during flight. In addition GPS were placed on the drifting sea ice and uplinked to Iridium (using JouBeh) sending positions every 15 minutes. This made it possible to receive updated positions of the corner reflectors in the air on the way to the validation sites by Iridium text messages. A simple drift software program was provided by R. Willatt, UCL, to account for the sea ice drift just by typing in the positions. As it turned out the sea ice were almost static during the survey period.

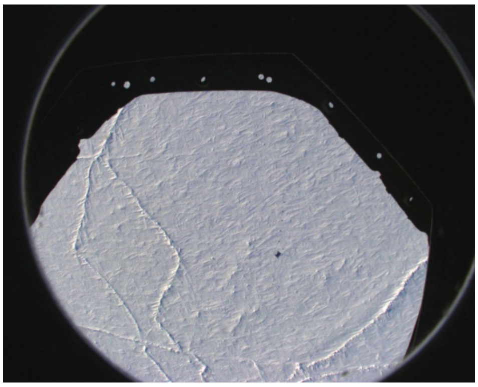


Figure 12: Corner reflectors and tarp markings seen from the aircraft (left) and tarp setup on the ice (right) Credits: K. Giles

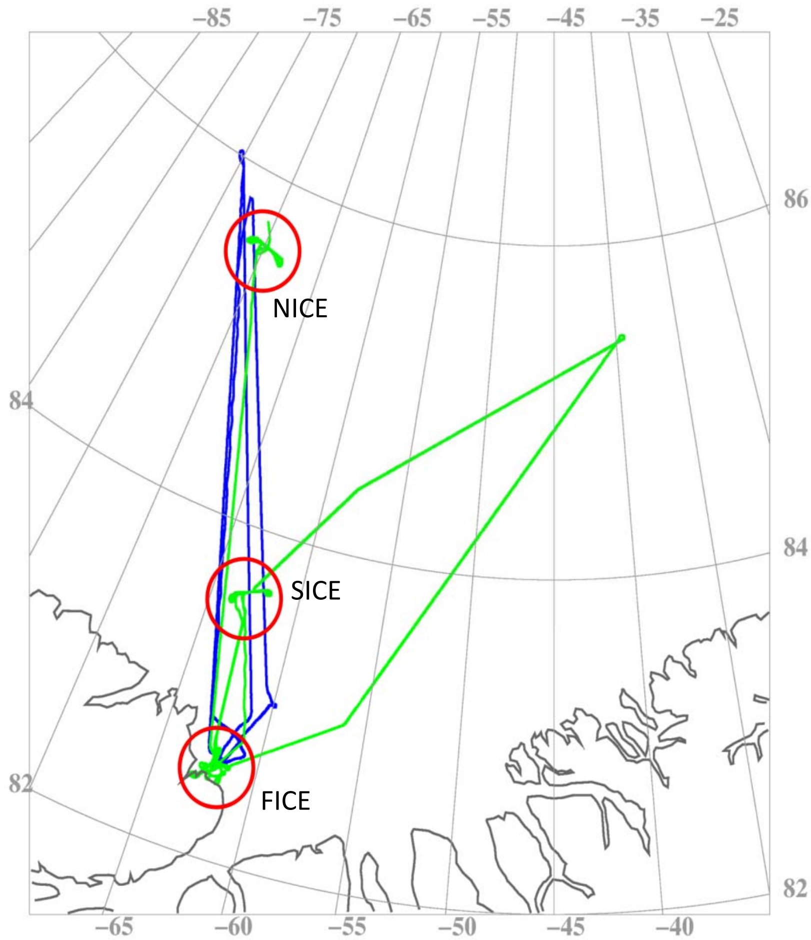


Figure 13: Flight tracks flown out of Alert. Red circles mark validation sites and dedicated CryoSat-2 underflights are blue lines. The eastern green track was flown to repeat tracks from previous years (2006 and 2008)

Each validation line was overflown multiple times, see overview Table 12. The ASIRAS data were primarily collected in low altitude low resolution mode (LAMa), however, two overflights of the SICE on April 15 were acquired in low altitude high resolution mode (LAM). An example of full resolution ALS data from the validation site SICE is shown in Figure 14.

Table 12: Overview of flights at sea ice validation sites out of Alert

Date	Number of overflights	Validation site
14-04-2011	8	NICE
15-04-2011	8	SICE
16-04-2011	2	SICE
16-04-2011	6	FICE
17-04-2011	2	FICE

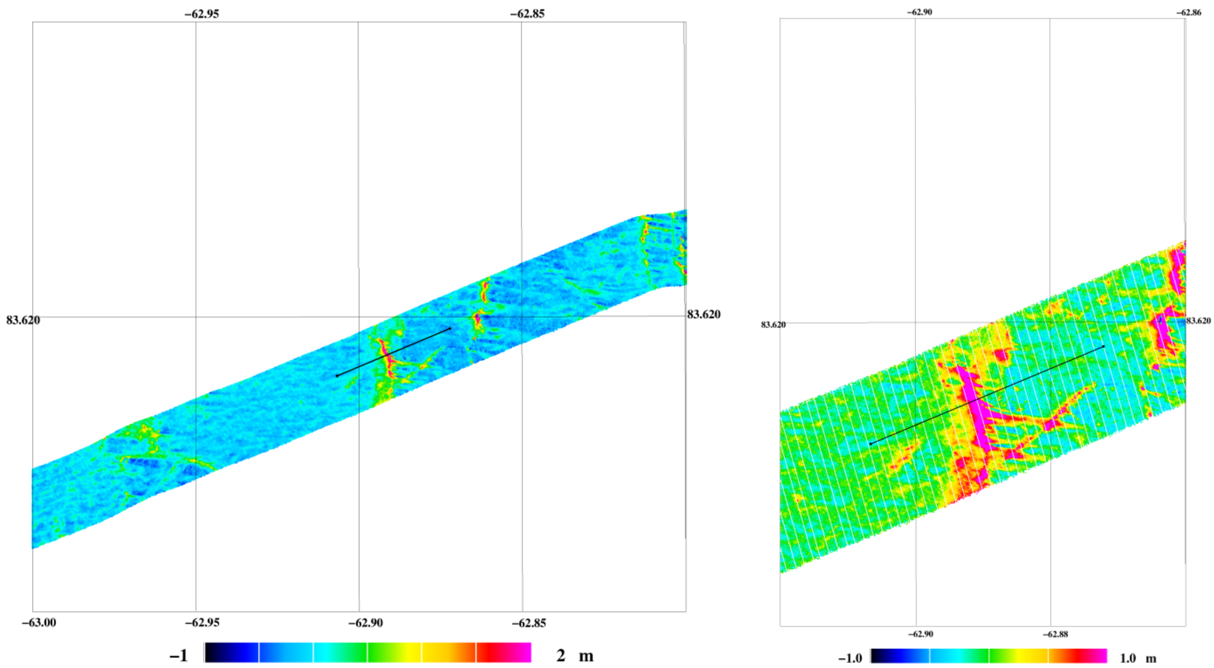


Figure 14: Laser scanner heights with referenced to the ArcGP geoid from the validation site (black line) SICE; overview left and detail right

CryoSat-2 tracks coincident flight with Polar-5

On April 15 an underflight of CryoSat-2 ground track 5399 (eastern blue track on Figure 13) was flown and on April 17 an almost parallel CryoSat-2 ground track 5428 (western blue track in Figure 13). The flights were flown in formation with Alfred Wegener Insitute (AWI) Polar-5, which carries an EM sounder below the aircraft. The Twin Otter was at about 1,000 ft above ground and a few minutes behind Polar-5 flying about 200 ft above ground. Both aircrafts kept the same ground speed of about

100 knots. During the flight the Twin Otter pilot had visual contact to the DC-3 and the pilots communicated via HF radio. This makes the coordination much easier, when compared to previous EM setup using a helicopter, and increases the accuracy of overlapping data acquisition. This is especially important over drifting sea ice. A detailed description of the airborne EM system and data is given in Chapter 3. The flight on April 15 was coordinated with NASA operation IceBridge flying from Kangerlussuaq with aircraft P-3. The P-3 surveyed the SICE validation site and part of the CryoSat-2 track with multiple airborne sensors for ice and snow retrievals. For further information see preliminary science flight report attached in Appendix 10.

The precision of the airborne ground tracks are illustrated in Figure 15, where track offsets are plotted as a function of cumulated frequency. Thus, 95% of the actual flown track was within 26 m of the CryoSat-2 ground track on April 15 and even more precise on April 17, where 95% of the track was within 15 m of the CryoSat-2 ground track.

Due to extreme cold conditions (-20 to -30^{o}C) and lack of proper GPS datation of the spare ALS (LMS Q-140i), no ALS data are available along the CryoSat-2 tracks using the DTU Space system. However, ALS data obtained with AWI Polar-5 are available, see Chapter 3.

First results (Skourup et al, 2011) of coincident ASIRAS heights referenced to the ArcGP geoid model using an 80% re-tracker (Stenseng, 2011) and CryoSat-2 (level 2) measurements show good agreement over sea ice, see Figure 16. Large negative offsets in heights are believed to originate from locking of the radar signal on off-nadir leads in the across track direction, as the SAR footprint is still a few kilometers wide. The implemented algorithm to discriminate between leads and sea ice is not persistent, however, this processing algorithm is expected to be improved in the updated ground processor, which are about to be implemented at the time of writing.

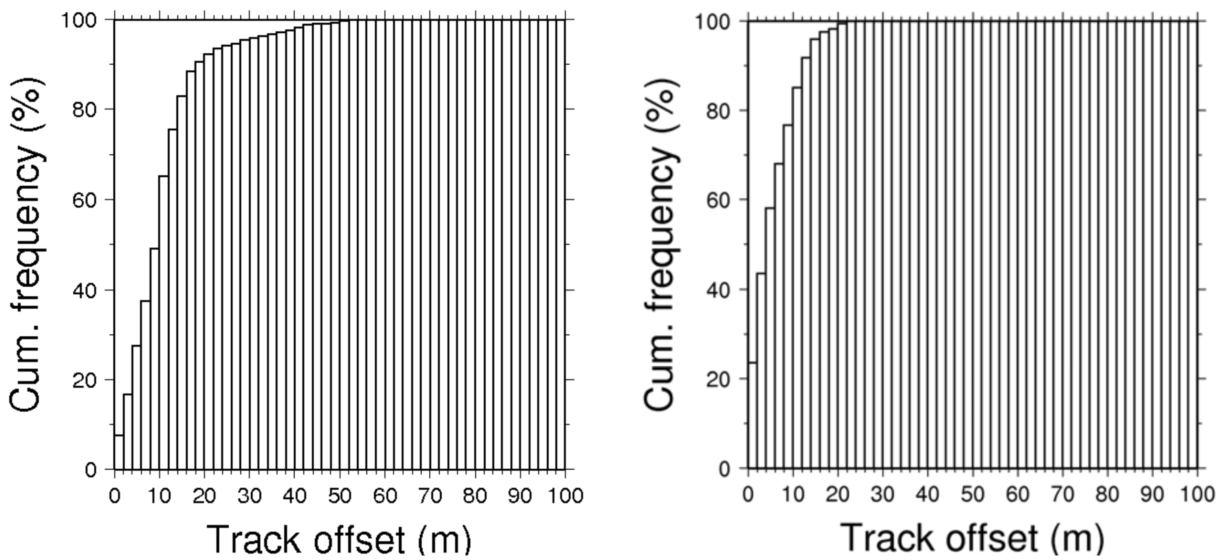


Figure 15: Precision of flight tracks along CryoSat-2 ground tracks on April 15 (left) and April 17 (right)

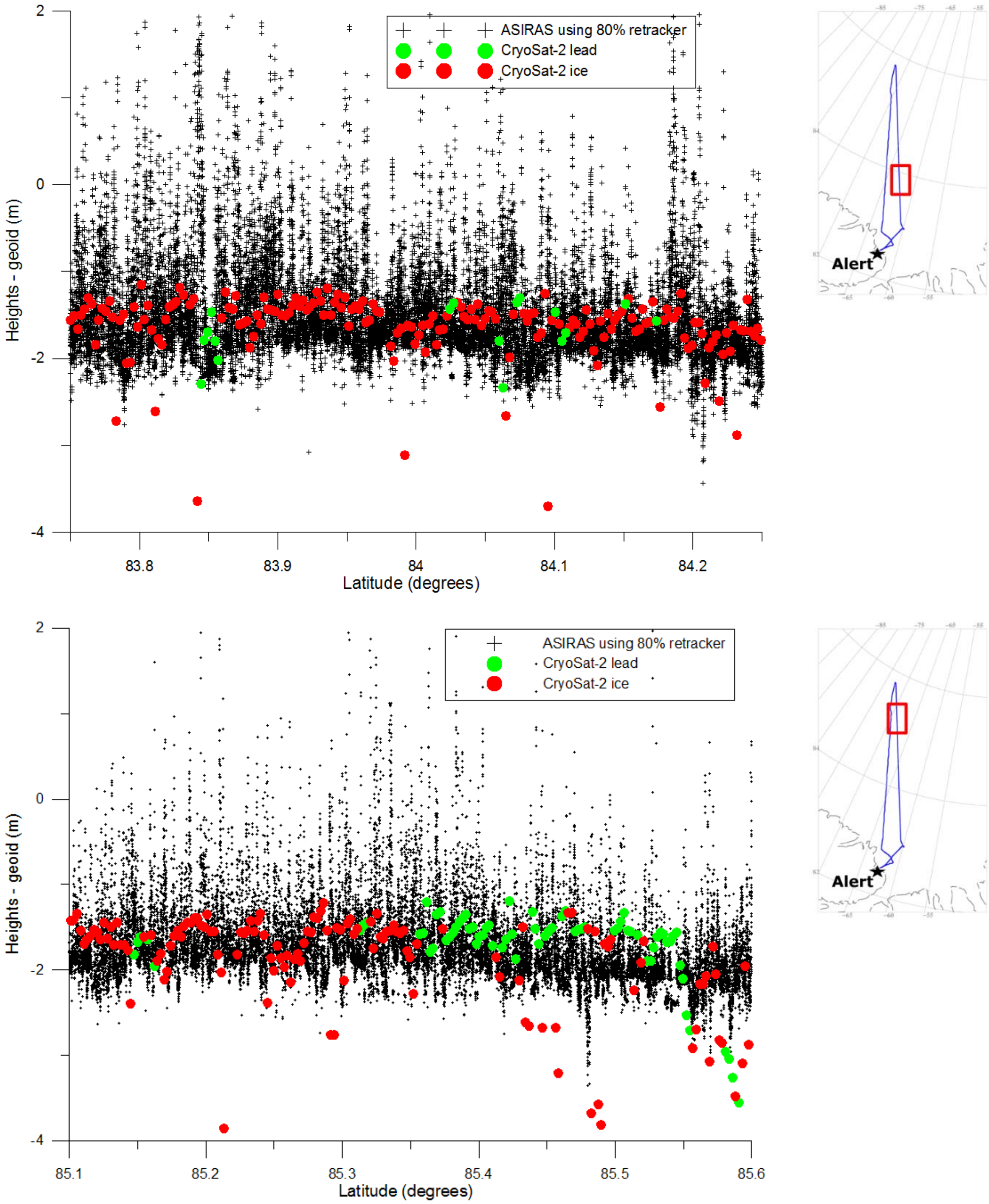


Figure 16: Examples of ASIRAS heights using an 80% re-tracker and CryoSat-2 heights with respect to ArcGP geoid model from CryoSat-2 ground track 5399 on April 15. Green dots represents CryoSat-2 heights flagged as leads and red dots are flagged as ice

2.7.2 EGIG line

The EGIG line were flown on April 26 (T15-T1) and April 27 (T1-EG6) and supplemented with a last flight on May 9 (T1-T15), to overfly a corner reflector placed at T15, see Figure 18. Four overflights of the corner reflector were carried out with the last pass at a flight altitude around 1,200 m to acquire ASIRAS data in High Altitude Mode (HAM). Analysis of previous years ASIRAS data at the EGIG line has proved that ASIRAS is able to detect annual layers of the Greenland ice sheet down to 15 m depth, corresponding to approximately 24 layers, in the dry snow zone near the ice divide (Stenseng, 2011). At the interior of the Greenland ice sheet, several layers were visible in the real-time display, see Figure 17.

On transit flight from Kangerlussuaq to Ilullisat on April 26, the flight was planned to follow CryoSat-2 ground track 5363 from April 13, see Figure 18. First results presented by Skourup et al (2011), show good consistency between the surface reflection of laser scanner measurements and ASIRAS using a 25% re-tracker (Stenseng, 2011), it was also illustrated that ASIRAS heights are unrealiable for roll-angles ±1.5 degrees.

Unfortunately, the flight track was about 16 km east of the CryoSat-2 ground track due to CryoSat-2 orbit maneuvers, in mid-April. The CryoSat-2 (level 2) data was moved to match the airborne track by use of ICESat DEM (DiMarzio, 2007). The near-coincident CryoSat-2 (level 2) and airborne laser scanner data over the Greenland Ice Sheet is not consistent and show biases between the two data sets by up to 50 m, see Figure 19. This is believed to improve with the reprocessed data using the updated ground processor, which are about to be implemented at the time of writing. For future campaigns it is important to ensure good contact to ESA regarding orbit changes.

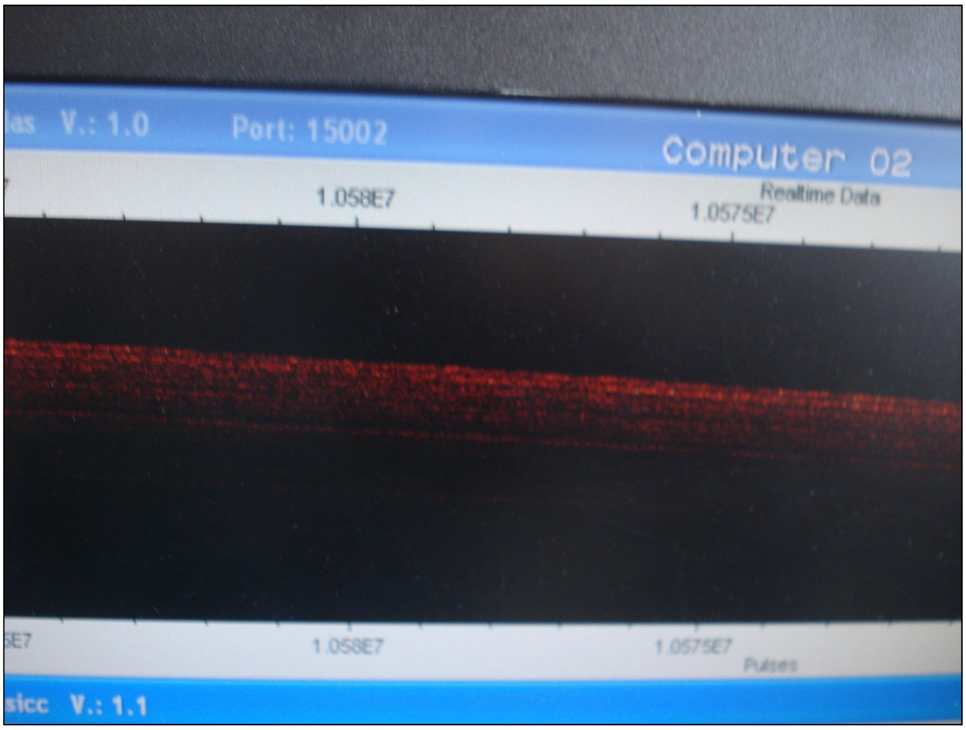


Figure 17: Layers visible in the ASIRAS real-time display in the middle of the Greenland ice sheet along the EGIG line

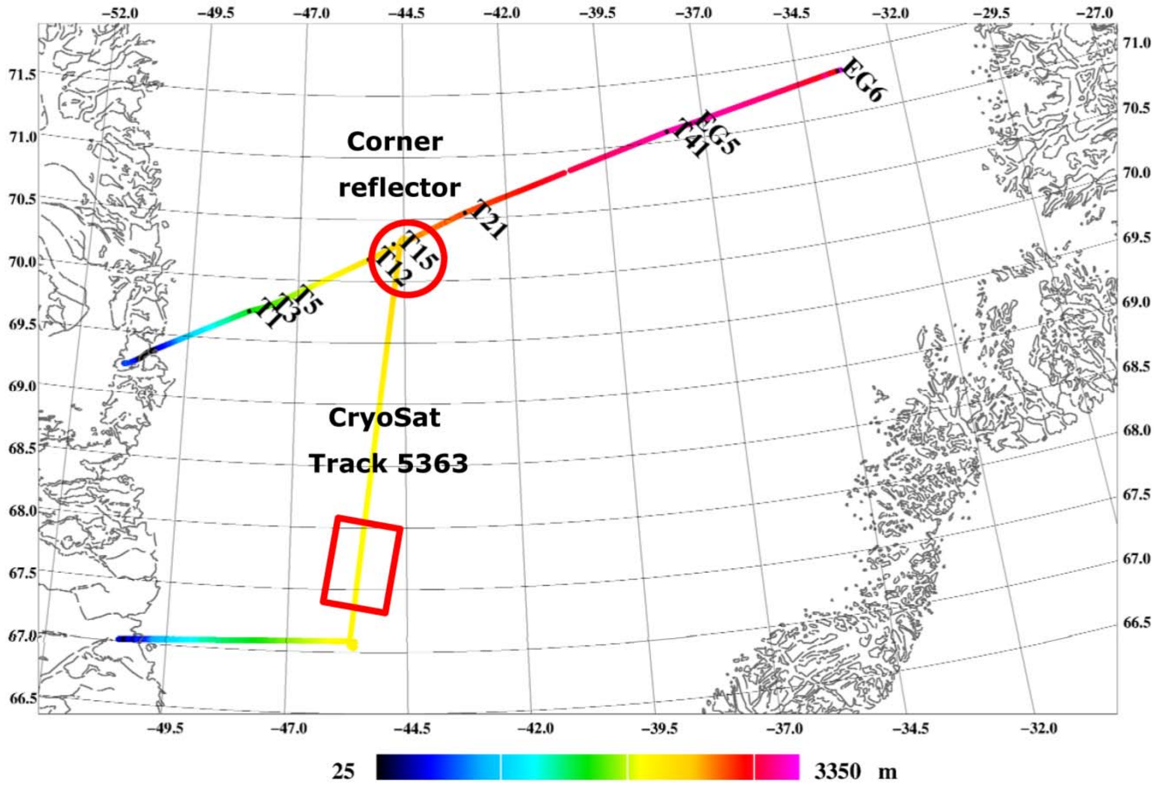


Figure 18: *Ellipsoidal heights of the Greenland ice sheet along the EGIG line (T1-EG6) and CryoSat-2 ground track from the vertical component of ALS*

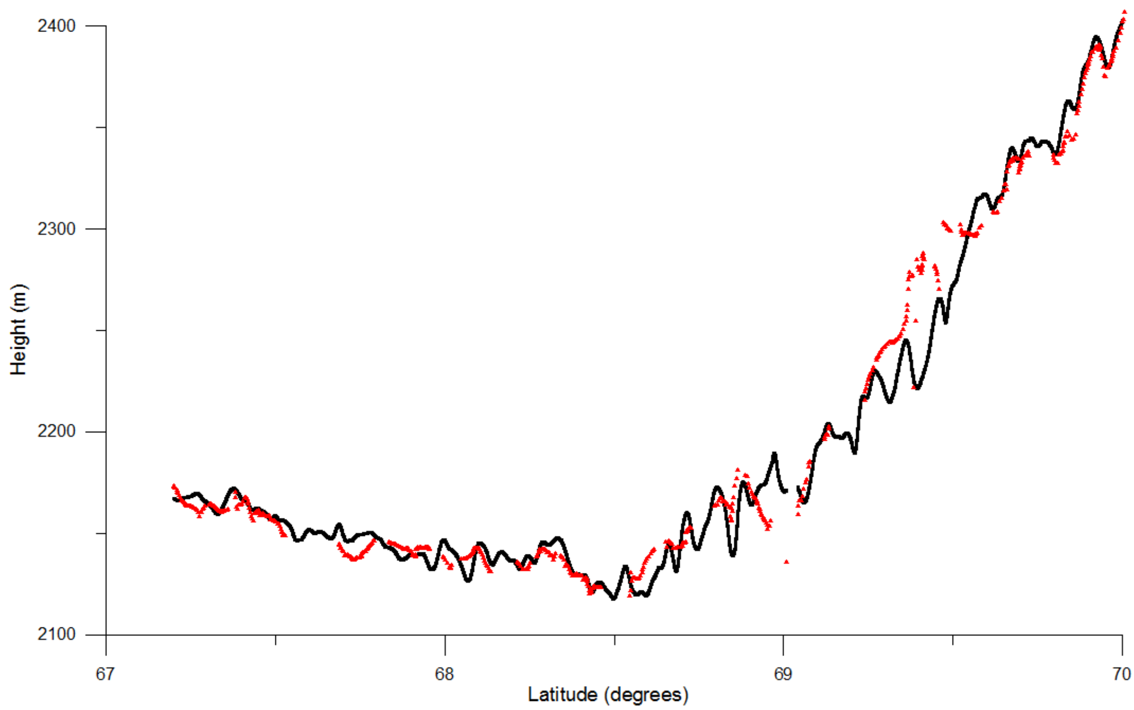


Figure 19: *Ellipsoidal heights of the Greenland ice sheet along CryoSat-2 ground track 5363 from vertical component of ALS (black dots) and CryoSat-2 level 2 data (red triangles)*

2.7.3 Austfonna

The survey of Austfonna ice cap were conducted on April 30. All six planned tracks were flown, see Figure 20. Two of the flights tracks were along CryoSat-2 ground tracks from May 4 and May 6, respectively. These tracks were surveyed by the ground team. In addition, four validation lines (471, 797, Eton East and NW Hartog) were repeated tracks from similar surveys conducted on May 1, 2006 and May 3, 2007. Along the flight lines five CR were erected. These are marked by triangles in Figure 20 and the position of the CR are listed in Table 10. In total the CR were overflown 8 times, see Table 13. According to the analysis of the ASIRAS data in Section 2.6.2 none of the corner reflectors were hit. Tracks from snowmobiles are clearly visible in the vertical photographs.

Table 13: Overview CR reflector overflights at Austfonna

ID	Track name	11AUST1	11AUST2	11AUST3	11AUST4	11AUST5
A	CryoSat May 4	X		X		
B	CryoSat May 6				X	
C	Line 472	X	X			
D	Line 797					
E	Eton East					
F	NW Hartog			X	X	X

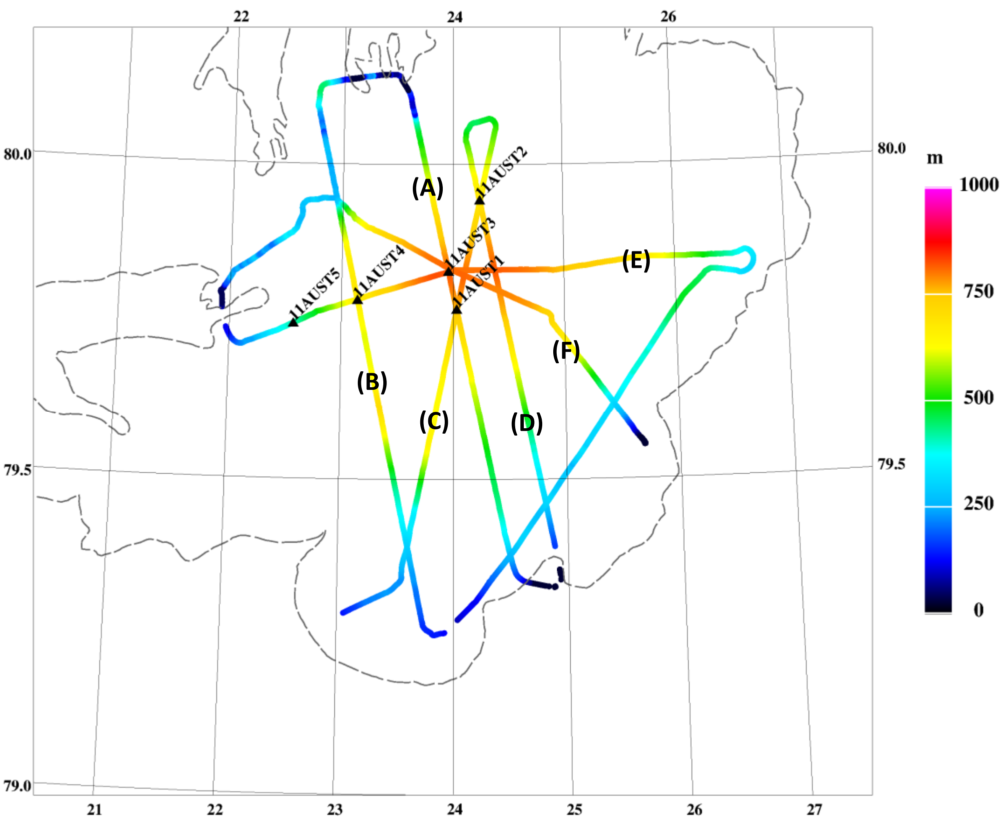


Figure 20: Ellipsoidal heights of Austfonna ice cap from vertical component of ALS

2.7.4 Devon ice cap

Devon ice cap flight, based out of Qaanaaq, took place on May 7 and was flown in very good flying conditions. According to priority and marginal weather in Qaanaaq only 4 lines were surveyed as listed in Table 14 and mapped in Figure 21, including CryoSat-2 ground track from May 1. The southestern part of the ice cap was covered in low clouds and the line SE crocker was cut short. CryoSat 623 and line 450 were repeat flights from May 6, 2008 and May 5, 2006.

Four CR were placed on the ice cap, three near summit (11DEV1, 11DEV3 and 11DEV4) and one CR north of summit (11DEV2). The exact positions are listed in Table 10, all corner reflectors were hit at least once.

Table 14: Overview CR reflector overflights at Devon ice cap

ID	Track name	11DEV1	11DEV2	11DEV3	11DEV4
A	CryoSat May 1	X	X	X	X
B	ASIRAS line 623	X		X	X
C	ASIRAS line 450	X		X	X
D	SE Crocker				

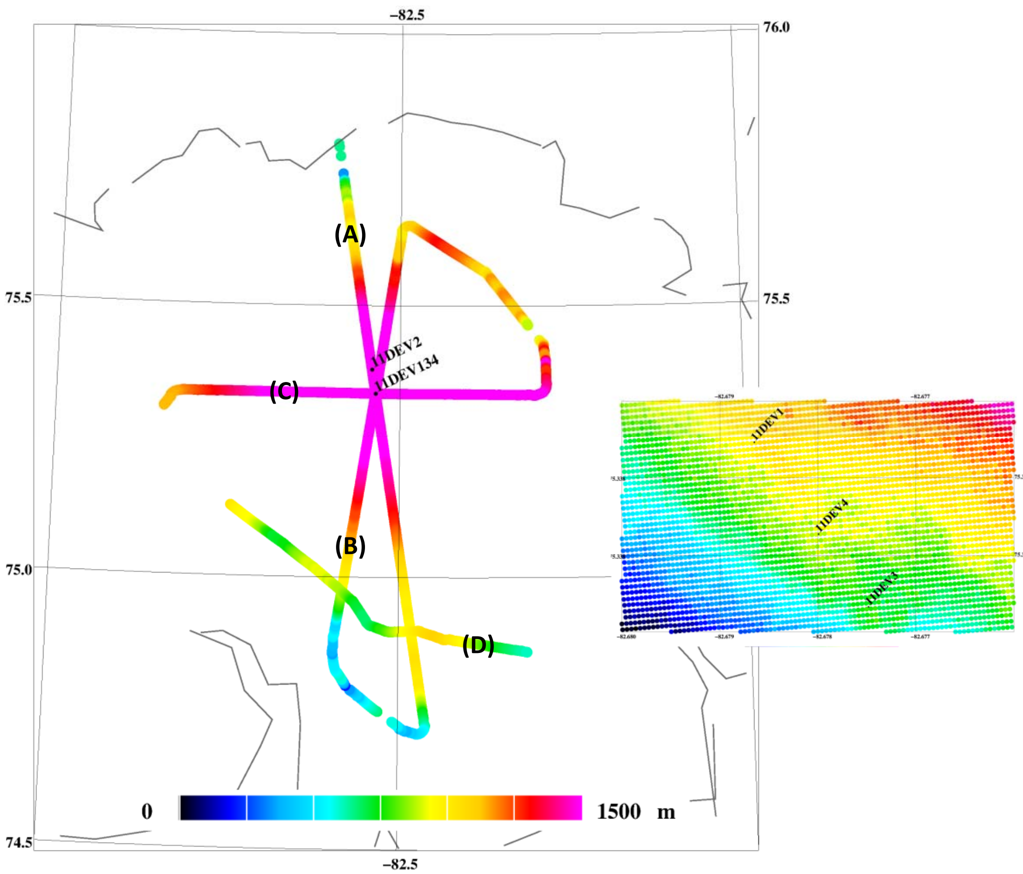


Figure 21: Ellipsoidal heights of Devon ice cap from vertical component of ALS with inset of the CR's at summit (right)

2.7.5 RV Lance

The research vessel RV Lance was overflown multiple times on April 30. Observations was focused on a validation line near the ship where extensive ground observations were done. The ship was located in the Fram Strait north of Svalbard close to the ice edge, where the sea ice is broken into small floes (typical size of 10-200 m in diameter). The wind was quite strong and the sea ice had drifted about 0.6 nm due east from aircraft take off to reaching the survey area. The ground team placed two CR approximately 1.3 km apart along the validation line. The validation site was overflown multiple times. The corner reflector closest to the RV Lance was obtained visually by direct guidance of the ground team, and the CR was visible in the webcam for the last 4 runs, see Figure 22.

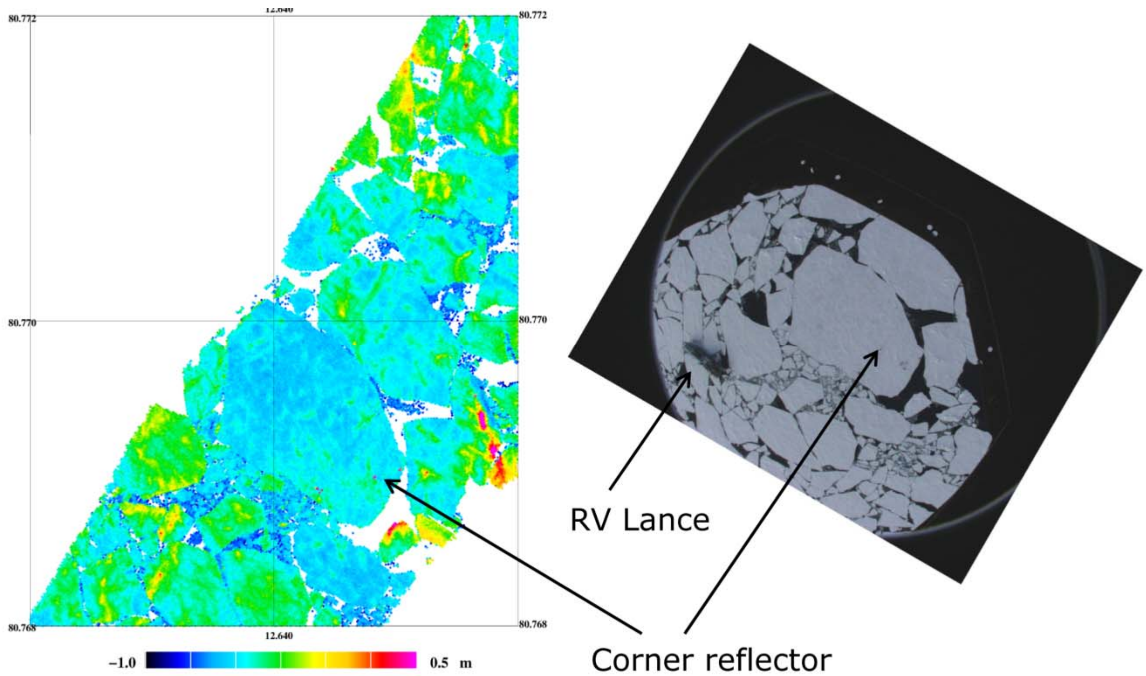


Figure 22: Full resolution laser scanner data given as heights above the geoid (left) at the validation site near RV Lance, together with vertical photography (right)

On the route to RV Lance a CryoSat-2 track 5599 from April 29 was surveyed. Due to the drift and long spatial time interval (~27 hrs) between CryoSat-2 pass and the airborne survey, a comparison of the data sets can be treated only as a statistical analysis of the sea ice in the area.

Using a lowest level estimation method (Hvidegaard and Forsberg, 2002) typical freeboard heights of 35-40 cm are observed, see plot of freeboard distribution in Figure 23. This corresponds to 1.9-2.2 m thick ice (using a freeboard to thickness conversion factor of 5.5), which is classified as thick first year ice or thin multiyear ice according to World Meteorological Organization (WMO) ice nomenclature.

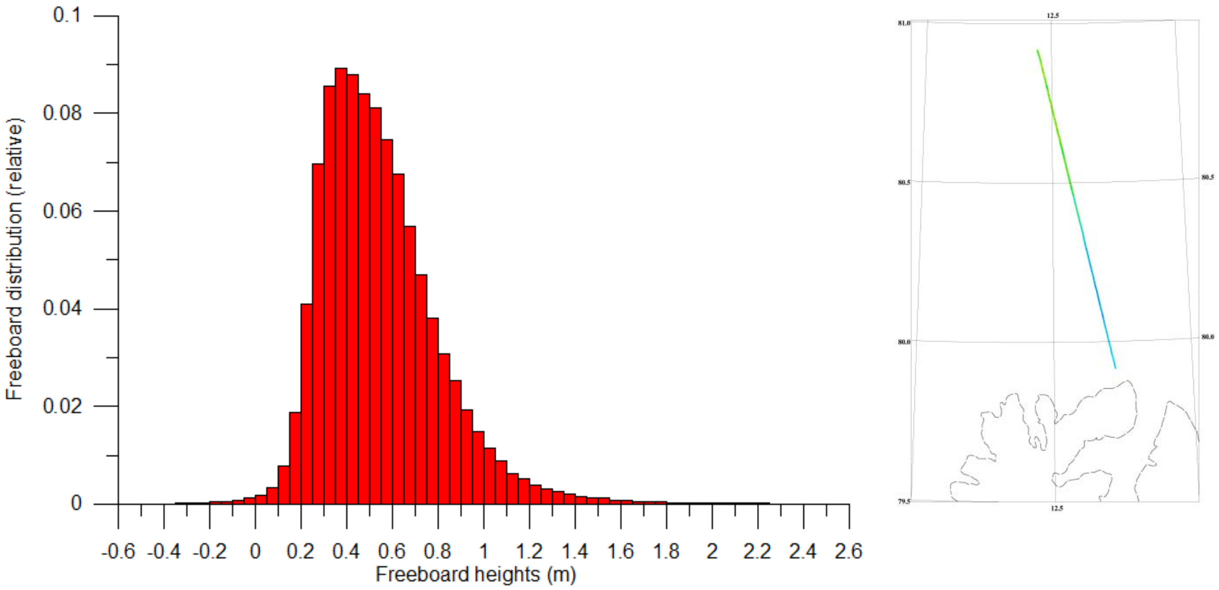


Figure 23: Distribution of sea ice freeboard heights (left) based on laser scanner measurements along CryoSat-2 track 5599 (right)

3 Airborne EM induction sounding

The activities of the Polar-5 during the CryoSat-2 Validation Experiment were based at the Canadian Forces Station in Alert between April 11 and April 18, 2011. The CryoVEx field campaign was embedded in a sea ice and atmosphere study of the western Arctic Ocean (PAM-ARCMIP: POLAR Airborne Measurements and Arctic Regional Climate Model Simulation Project). The surveys of the Arctic Ocean in spring 2011 are marked in Figure 24.

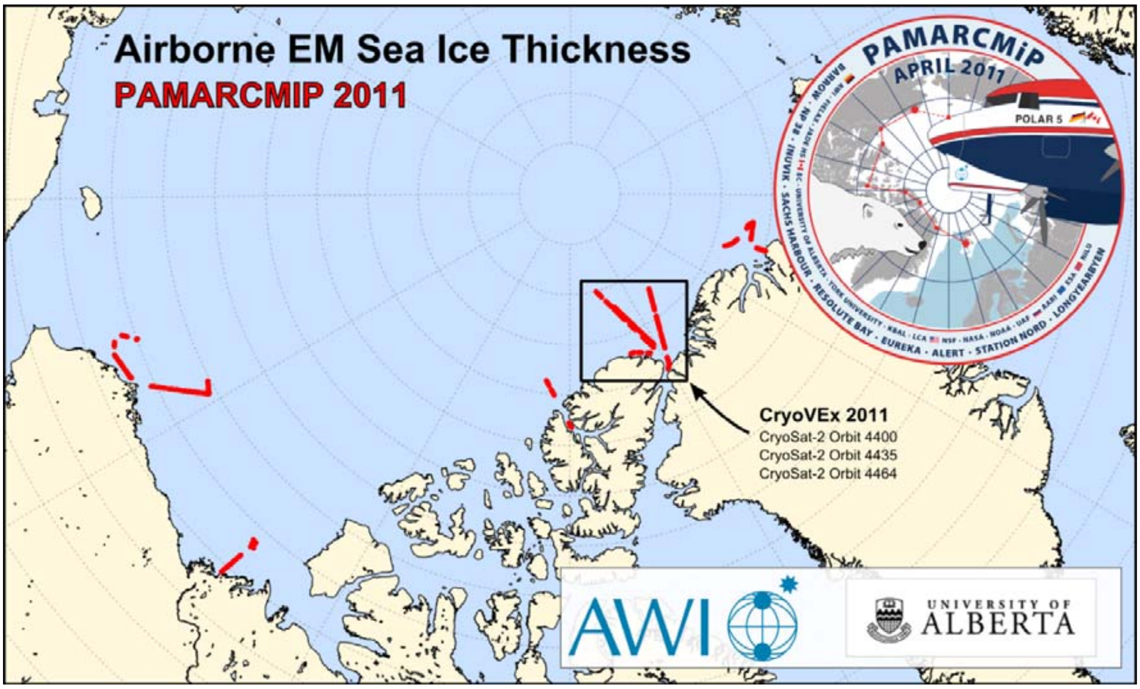


Figure 24: Airborne EM sea ice thickness profiles collected in spring 2011 during the PAM-ARCMIP and CryoVEx field campaigns. The black box marks the location of the CryoSat-2 Validation Experiment in the Lincoln Sea

Figure 25: AWI Polar-5 aircraft with EM induction sounder in front, DTU Space Twin Otter with ASIRAS and ALS together with Twin Otter used for validation work, CFS Alert

3.1 Airborne EM Sea Ice Thickness Retrieval

The retrieval of sea ice thickness with airborne EM is based on the contrast of electrical conductivity between sea water and sea ice, which can be sensed by low-frequency electromagnetic field. Because the airplane is a significant conductor, the sensor (EM-Bird) can be lowered with a winch on a 200 ft long cable to an altitude around 50 ft over the ice surface. During these measurements, the aircraft maintains an altitude of approximately 200 ft, see illustration Figure 26.

Since the distance to the top of the sea ice layer is measured by a laser-altimeter, the snow depth is included in the final ice thickness product. Therefore, AEM sea ice thickness always refers to total (snow plus ice) thickness.

The low temperatures in early April in the target area cause a significant temperature driven sensor drift. To correct for this drift, the EM-Bird is lifted to an altitude for zero-level measurements in regular intervals (around 10 to 15 minutes). During these ascends and following descends, no sea ice thickness data is available.

The general accuracy of airborne EM data is +/- 0.1 m over level sea ice. The thickness of deformed sea ice can be underestimated by as much as 60% in maximum thickness. Recent (yet unpublished) studies indicate however, that the mean thickness of longer sections is comparable to the real ice thickness, because deformed features are also overestimated in lateral extent.

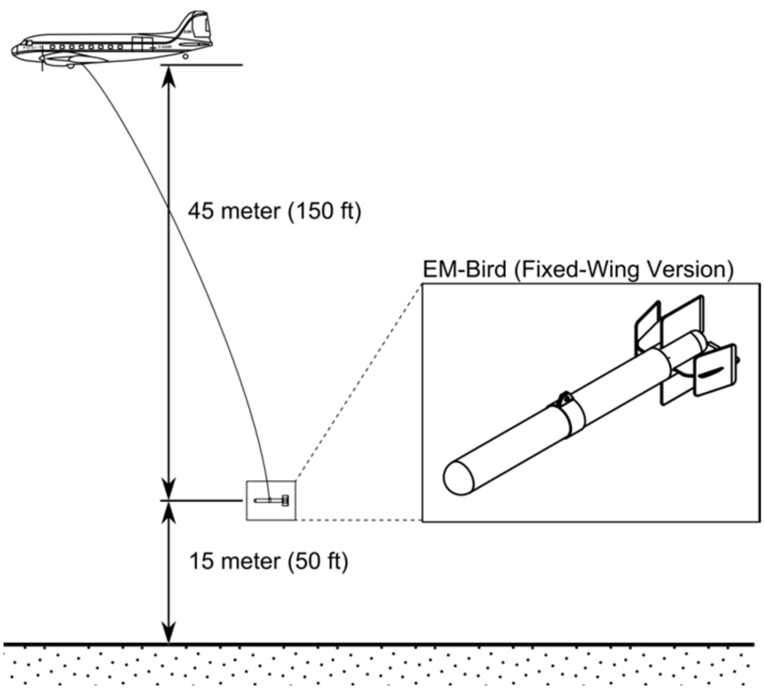


Figure 26: Airborne EM sea ice thickness retrieval with fixed-wing aircraft (Photo: Christian Haas)

3.2 Data Acquisition

The flight program comprised 4 dedicated sea ice flights: Three surveys of a CryoSat-2 ground-track and one overpass over the southern (first-year) validation site.

Date	Filename	Comment
14-04-2011	HEM_CRV11_20110414T143255_20110414T163111.dat	[CryoSat-2 Orbit 5364] The Polar-5 flight track followed the CryoSat-2 overpass one day earlier (2011/04/13), because of no-fly conditions on that day. Sea ice drift was generally low, especially in the southern part of the profile
15-04-2011	HEM_CRV11_20110415T152401_20110415T164026.dat	[CryoSat-2 Orbit 5399] Coincident flight with the ASIRAS Twin-Otter at the time of CryoSat-2 pass
16-04-2011	HEM_CRV11_20110416T195222_20110416T195536.dat	[Southern Validation Site] One overpass of the southern (first-year) validation site. Technical problems with the EM-Bird caused slightly inaccurate geolocation of the ice thickness data.
17-04-2011	HEM_CRV11_20110417T140623_20110417T155439.dat	[CryoSat-2 Orbit 5428] Coincident flight with the ASIRAS Twin-Otter at the time of CryoSat-2 pass

Overview plots with the flight track and ice thickness histograms are given in the Figure 27 to Figure 30. The file name convention and data format are given in Appendix 3 and 4.5, respectively.

3.2.1 Data Quality

While the measurements in high altitude are used to remove near-linear sensor drift, the absolute calibration of the AEM ice thickness data can be checked at spots of open water. Due to the lack of even small leads in the southern part of all profiles, the AEM ice thickness data may have a higher uncertainty than in the northern parts, where sea ice conditions allowed more leads to open. An additional uncertainty factor in the southern part of the profiles is the higher non-linearity of the sensor drift, because the instrument temperature was not yet stable in the beginning of the survey.
In particular, the survey over the southern validation site is affected by non-linear instrument drift. A quality check revealed that the first overpass yielded not entirely reliable results, therefore only one out of two overpasses is included in the official release. During this flight the GPS system of the EM-Bird was not functional. Therefore the positions had to be calculated by the GPS position of the aircraft, which gives a less accurate geolocation of the EM-Bird ice thickness data. How the airborne EM thickness data compares with the ground-EM data can be seen in Figure 30.

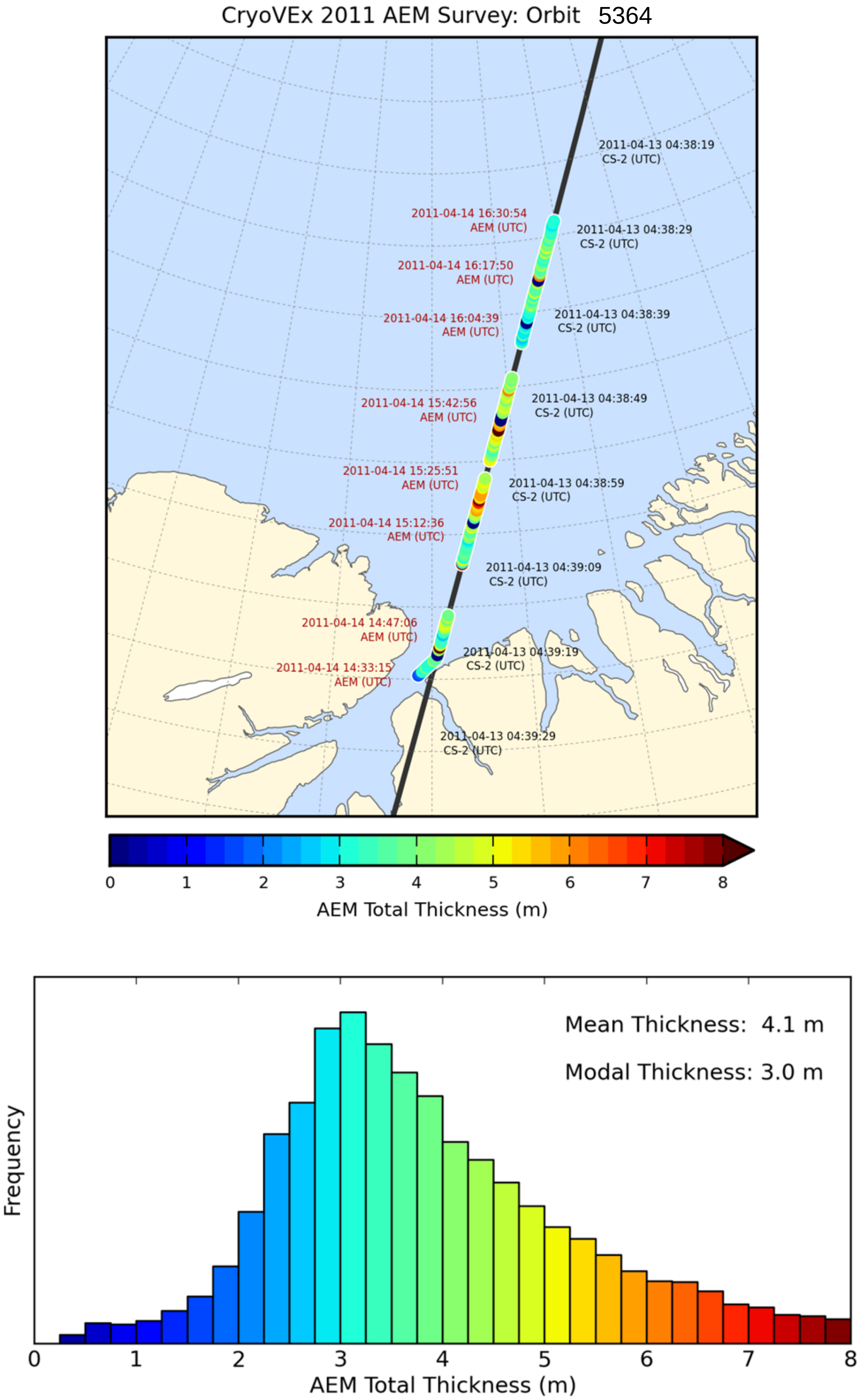
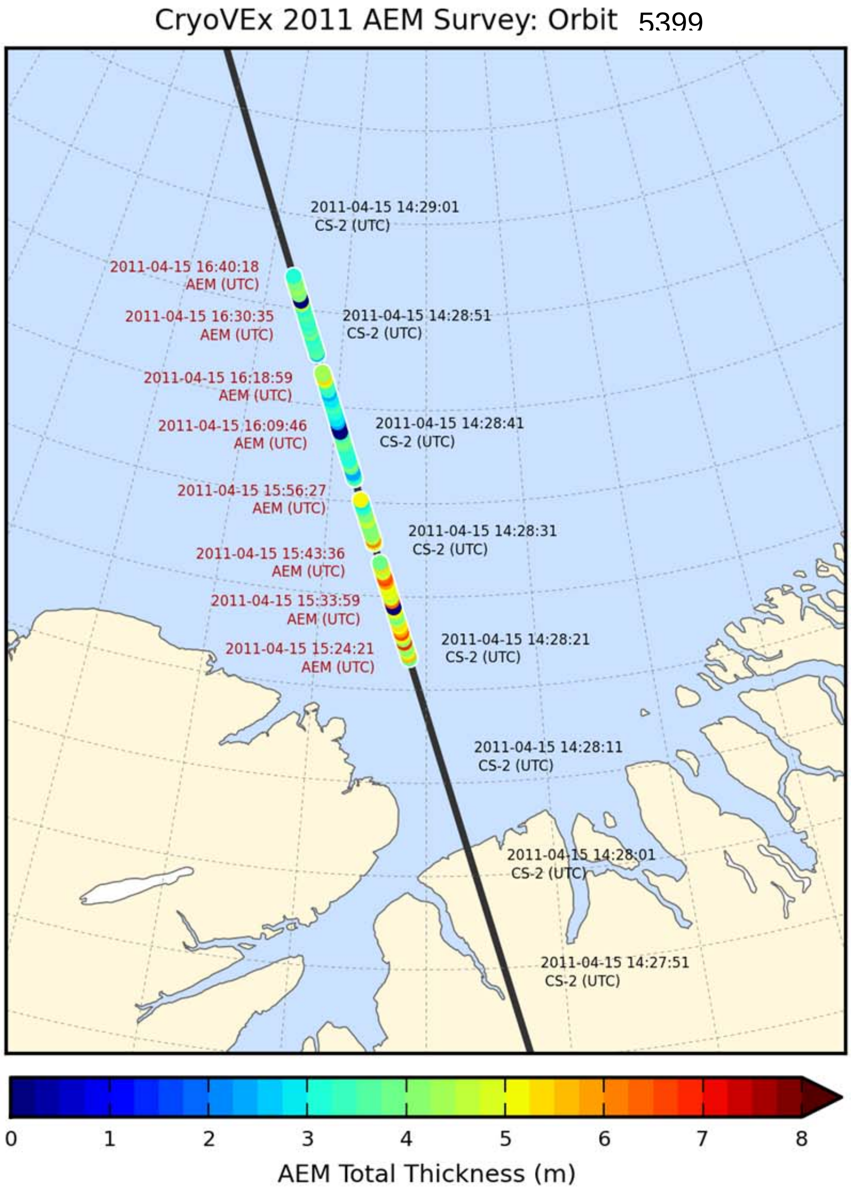


Figure 27: Airborne EM flight track and sea ice thickness on April 14



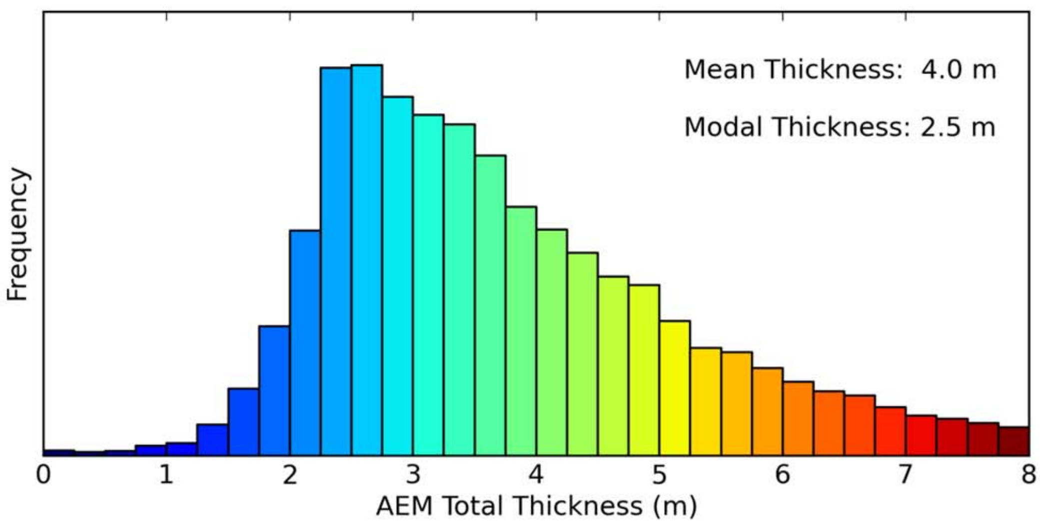


Figure 28: Airborne EM flight track and sea ice thickness on April 15

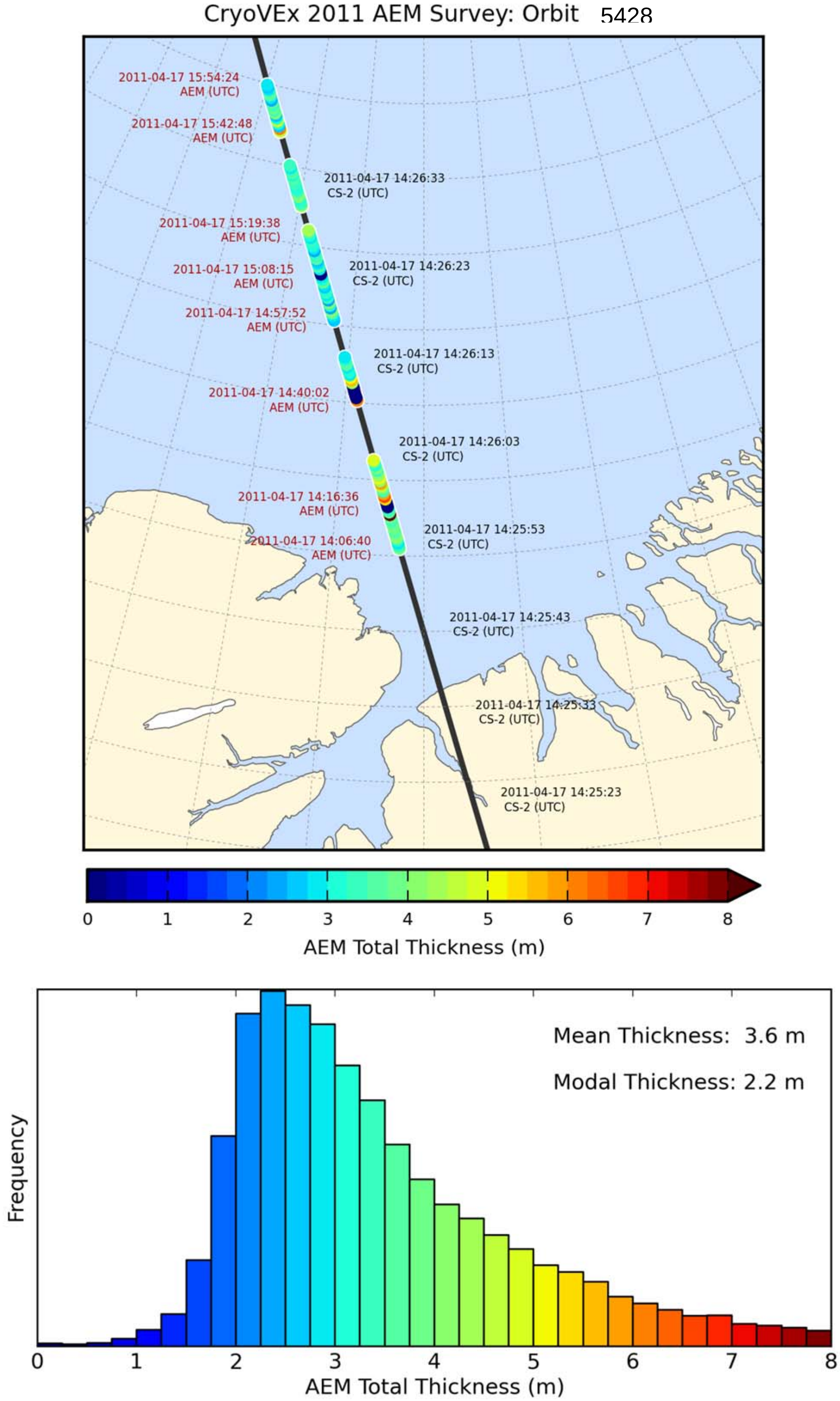


Figure 29: Airborne EM flight track and sea ice thickness on April 17.

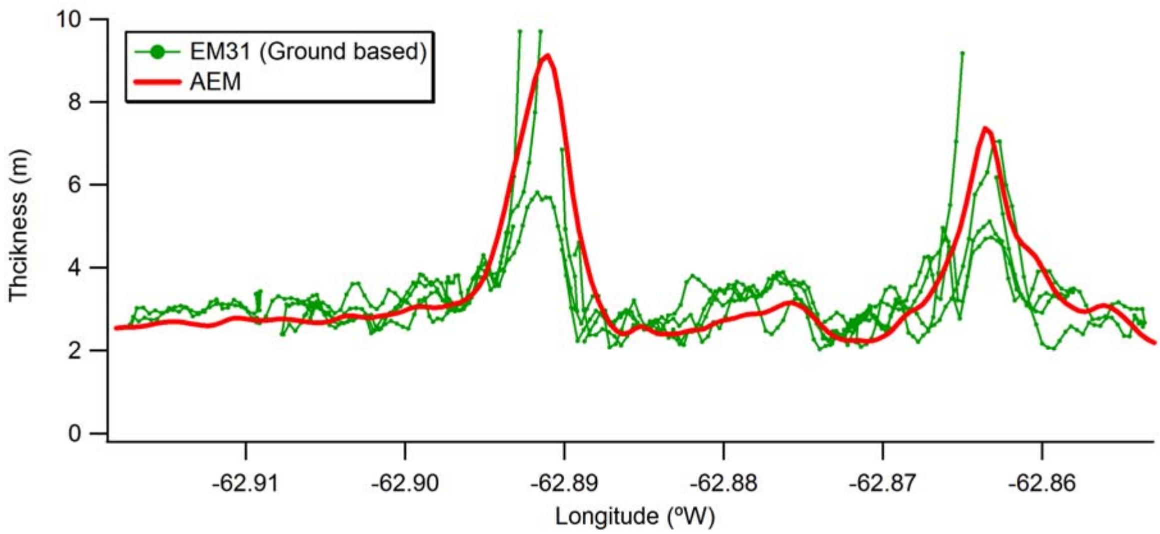


Figure 30: Airborne EM flight track and sea ice thickness on April 16. The lower figure shows a comparison between airborne and ground-based EM ice thickness data

4 Conclusion

The CryoVEx 2011 campaign was a success. A total of about 100 flight hours, covering about 23 500 km, was flown with ASIRAS and ALS using DTU Space charted Twin Otter. The experiment demonstrated great collaboration and timing between a large group of European, Canadian and US scientists. The effort involved airborne activities coordinated with AWI Polar-5 carrying an EM inducting sounder and ground teams on five different validation sites. In addition, collaboration with US NASA Icebridge team was done. A broad suite of data of the sea ice, Greenland ice sheet and the local ice caps Devon and Astfonna has been collected giving a unique data set to optimize CryoSat-2 Level 1b and Level 2 retrieval algorithms.

In contrast to previous validation experiments, the EM ice thickness retrieval was conducted with a fixed-wing airplane, and not by helicopter. The use of the Polar-5 results in surveys of highly improved range and enables tandem flights with the ASIRAS Twin-Otter with very short temporal offsets over long distances, which increases the accuracy of overlapping data acquisition.

High navigational precision was obtained throughout the campaign, especially over CR sites. CR's were all successfully hit with ASIRAS on the sea ice out of CFS Alert, the EGIG line and Devon ice cap. On Austfonna and the RV Lance validation site, none of the reflectors were observed in the ASIRAS data, at RV Lance primarily due to unknown position of the CR's due to the large drift of the sea ice.

Based on CR analysis and comparison to coincident ALS runway overflights it is concluded that level_1B data measured with upgrade ASIRAS instrument and processed with the ASIRAS processor version ASIRAS_04_03 shows no time shifts and an overall good quality.

The ALS data is of high quality and airborne validation data exists for all the validation sites with standard deviation about 5 cm. Due to extreme cold conditions (-20 to -30°C) and lack of proper GPS datation of the spare ALS used throughout the first part of the campaign, no ALS data are available for several of the flights out of CFS Alert, including the CryoSat-2 ground tracks on April 15 and 17 using the DTU Space system. However, data has been obtained on the main validation sites, and ALS data obtained with AWI Polar-5 is available, on request at AWI, for flight along CryoSat-2 ground track on April 15.

The general accuracy of airborne EM data is +/- 0.1 m over level sea ice. The thickness of deformed sea ice can be underestimated by as much as 60% in maximum thickness using this method. Recent (yet unpublished) studies indicate however, that the mean thickness of longer sections is comparable to the real ice thickness, because deformed features are also overestimated in lateral extent.

Upcoming CryoVEx 2012 airborne campaign will focus on long transects of CryoSat-2 ground tracks (both in SAR and SARin mode) in the Arctic Ocean north of CFS Alert and Eureka, to obtain coincident ASIRAS, ALS and AEM data. This will be followed by measurements of the Greenland ice sheet and the local ice caps, Devon and Austfonna coordinated with ground teams.

5 References

Cullen, R.: CryoVEx Airborne Data Products Description, Issue 2.6.1, ESA, Ref. CS-LI-ESA-GS-0371, 2010

DiMarzio, J., A. Brenner, R. Schutz, C. A. Shuman, and H. J. Zwally. GLAS/ICESat 1 km laser altimetry digital elevation model of Greenland, [list the dates of the data used]. Boulder, Colorado USA: National Snow and Ice Data Center. Digital media. 2007

Helm, V. , Hendricks, S. , Göbell, S. , Rack, W. , Haas, C. , Nixdorf, U. and Boebel, T.: CryoVEx 2004 and 2005 (BoB) data acquisition and final report , Alfred Wegener Institute, Bremerhaven, Germany, ESA contract C18677/04/NL/GS, 2006

Hvidegaard, S. M., R. Forsberg, V. Helm, S. Hendricks, H. Skourup, L. Stenseng, S. Hanson and C. Haas: CryoVEx 2008. DTU Space, Technical Report 2, 2009

Hvidegaard, S.M. and R. Forsberg: Sea-ice thickness from airborne laser altimetry over the Arctic Ocean north of Greenland. Geophysical Research Letters, 29(20):1952, 2002

Pedersen, L. T., R. T. Tonboe, M. B. Jensen, G. Dybkjær, M. Nissen, J. Rasmussen, S. M. Olsen, H. Skourup, R. Saldo, and R. Forsberg: KANUMAS MET/ICE/OCEAN Overview Report 2011 - West Greenland. Technical Report produced for Bureau of Mineral and Petrol, Greenland, DMI publication, Copenhagen 2011

Pedersen, L. T., R. T. Tonboe, M. B. Jensen, G. Dybkjær, M. Nissen, J. Rasmussen, S. M. Olsen, H. Skourup, R. Saldo, and R. Forsberg: KANUMAS MET/ICE/OCEAN Overview Report 2011 - East Greenland. Technical Report produced for Bureau of Mineral and Petrol, Greenland, DMI publication, Copenhagen 2011

Skourup, H., I. Einarsson, L. S. Sørensen, R. Forsberg, L. Stenseng, S. Hendricks, V. Helm, M. Davidson: ESA CryoVEx 2011 airborne campaign for CryoSat-2 calibration and validation. Oral presentation at American Geophysical Union (AGU) fall meeting, San Francisco, California, USA. December 5-9, 2011

Stenseng, L.: Polar Remote Sensing by CryoSat-type radar altimetry. Phd-thesis, DTU Space, 2011

Stenseng, L., S. M. Hvidegaard, H. Skourup, R. Forsberg, C. J. Andersen, S. Hanson, R. Cullen, and V. Helm: Airborne Lidar and Radar Measurements in and around Greenland, CryoVEx 2006. Danish National Space Center, Technical Report 9, 2007

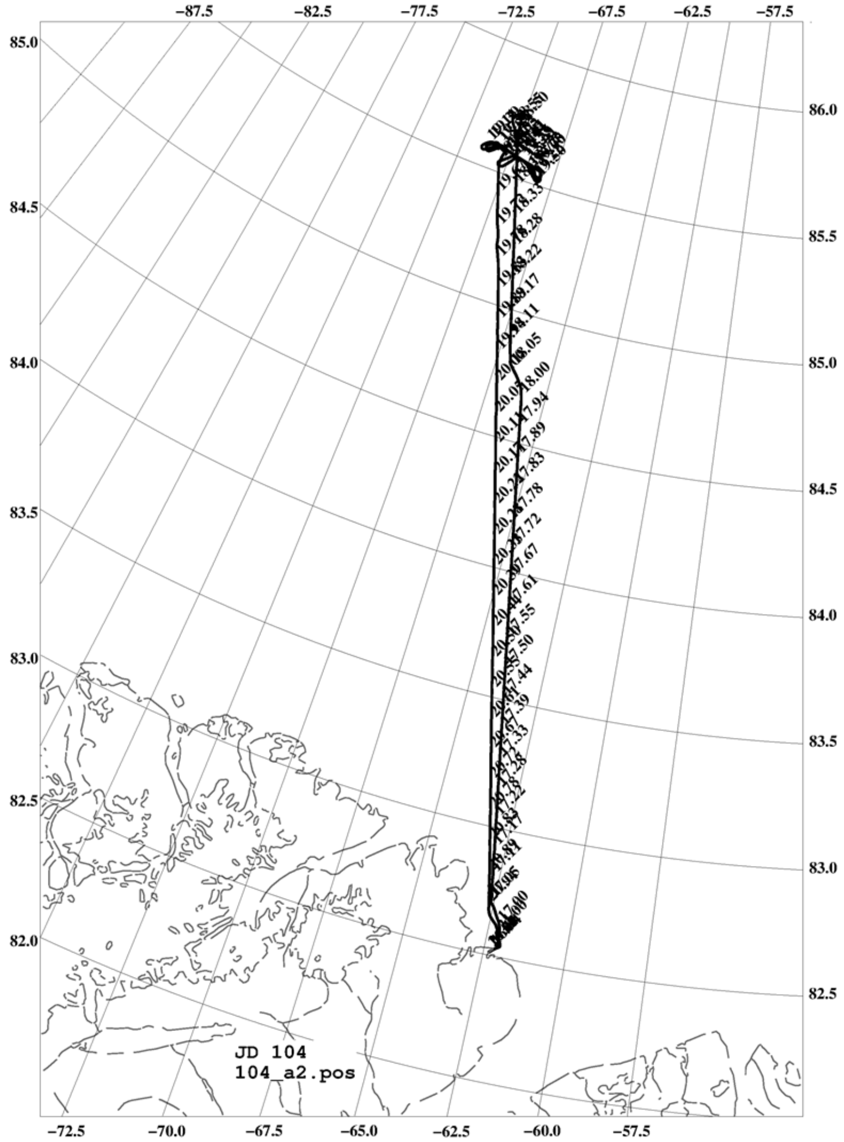
1 APPENDIX Operator logs

DOY 104, 14-05-2011: YLT-NICE-YLT

1620	Startup system
1647	System up and running
	No laser scanner - low temp
1655	Take off, YLT
1838	R1, CR1-CR2, 300m, off the line
18	R2, CR2-CR1, 300m
1854	R3, CR1-CR2, 300m
1900	R4, CR2-CR1, 300m
(1905)	R5, CR1-CR2, 300m
1917	R6, CR2-CR1, 300m
1926	R7, CR1-CR2, 300m
1933	R8, CR2-CR1, 300m
	EGI input shread stopped
2056	Shut down ASIRAS
2100	On ground, YLT

ASIRAS log

overflight over CR1/CR2
Reflector visible in SDS no. 1,9
Reflector visible in data at t=4961,6499,6562?



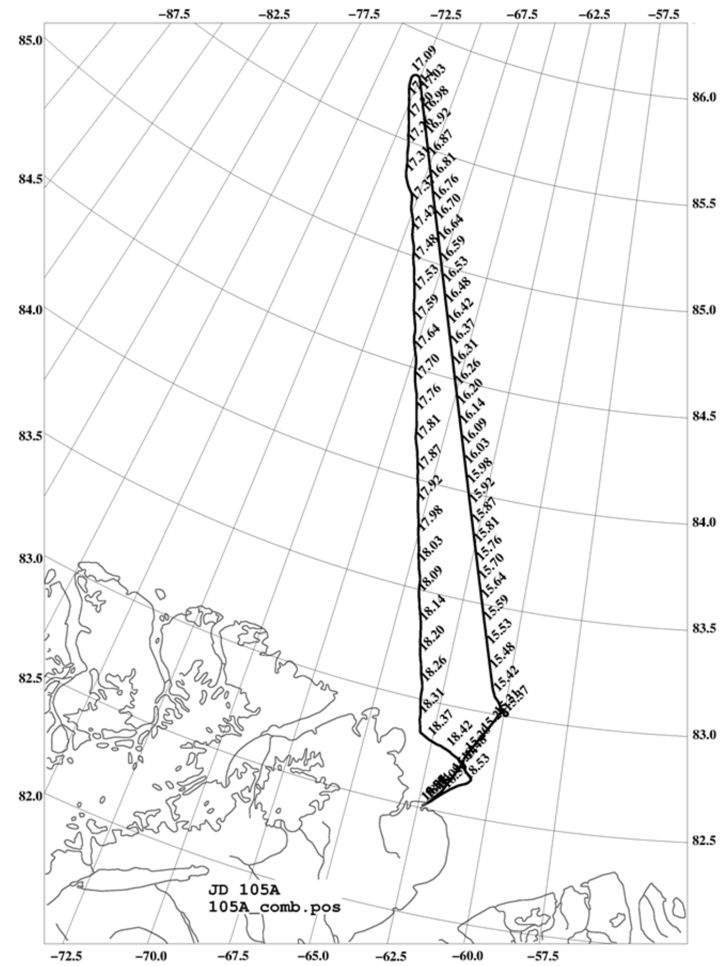
DOY 105A, 15-05-2011: YLT-CRYOSAT-YLT

coincident flight wiht POLAR-5

1441 Start up system
1456 Polar-5 takes off
Scanner up and running (pre-heated with Herman Nelson)
1500 Taxi
1502 Take off
150900 Scanner file, 300m
1520 Teardrop
C4435_1
Approximate 100kn
1525 On the line
1537 C4435_2
1540 Scanner too cold, failed to read data
1554 C4435_3
1612 C4435_4
1630 C4435_5
1647 C4435_6
1659 Polar-5 on route YLT
Increase speed to 130kn
C4435_7
No survey on route YLT
1839 On ground, YLT

ASIRAS log

Filename: A110415_00_1_NN.dat
Time synchronisation
GPS time 155700
Asiras cpu time 175028
[a posteriori note, IE: there is also a gps time-tag in the asiras log file]
1900 stop measurements
1902 calibration
A110415_00_1.ca1
A110415_00_2.ca1
A110415_01_1.ca2
GPS time 172820
Asiras cpu time 192148

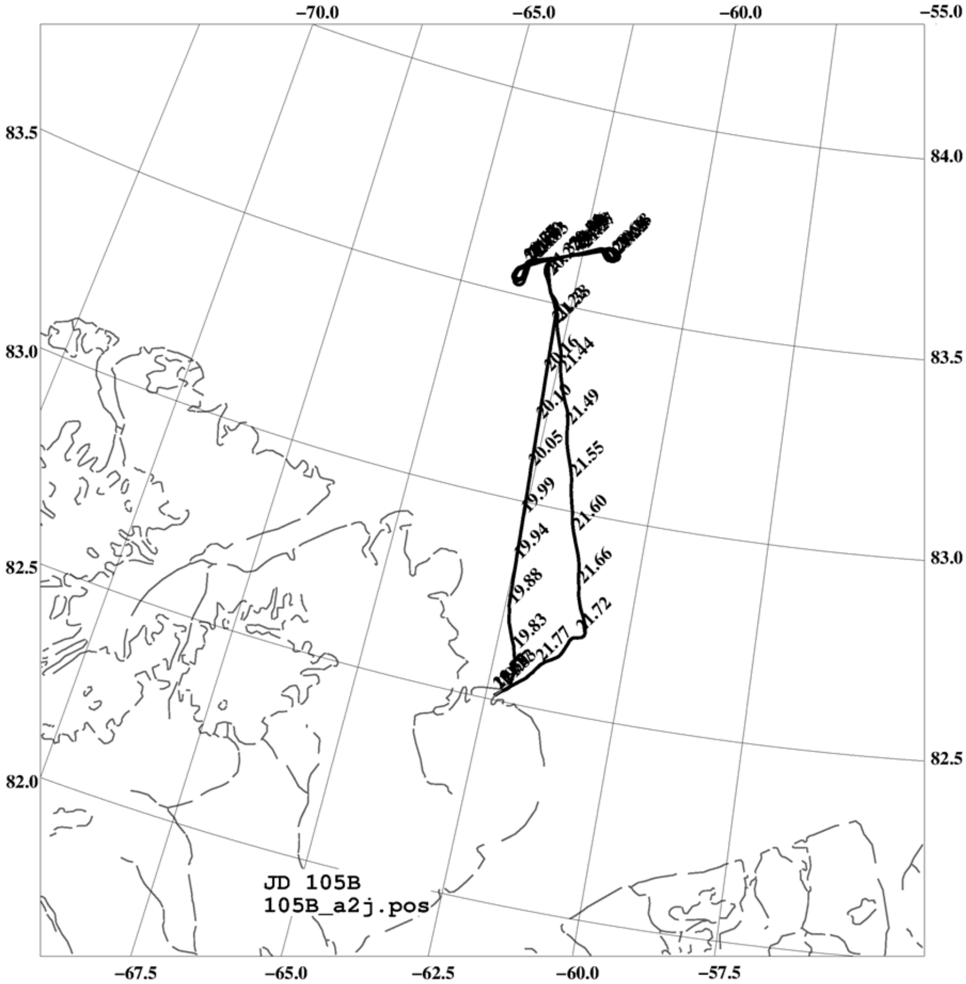


DOY 105B, 15-05-2011: YLT-SICE-YLT

1945 Airborne
EGI not aligned, but nav-mode
2018 R1, CR40-CR50, 300m, LAM-A
2026 R2, CR50-CR40, 400m, LAM-A
2035 R3, CR40-CR50, 400m, LAM-A
2043 R4, CR50-CR40, 400m, LAM-A
2051 R5, CR40-CR50, 400m, LAM-A
2059 R6, CR50-CR40, 400m, LAM-A
2108 R7, CR40-CR50, 400m, LAM
2117 R8, CR50-CR40, 400m, LAM
EGI logging input shread stopped
On route YLT
SICE-YLT no survey, download data
2150 On ground, YLT

ASIRAS log

Filename: A110415_01_NN.dat
2018 R1 CR40-CR50 webcam OK, SDS 0
2026 R2 CR50-CR40 webcam ok, radar ok, SDS 1
2035 R3 CR40-CR50 webcam ok, radar ok, SDS 2, event marker 1
2043 R4 CR50-CR40 webcam ok, radar ok, SDS 3, event marker 2
2051 R5 CR40-CR50 webcam ok, radar ok, SDS 4, event marker 3
2059 R6 CR50-CR40 webcam ok, radar ok, SDS 5, event marker 4
Shift to high data rate mode (~37500Hz instead of ~9500Hz)
File name: A110415_02_NN.dat
Overflying continues
2108 R7 CR40-CR50 webcam ok, radar ok, SDS 0, event marker 1
2117 R8 CR50-CR40 webcam ok, radar: only wage signal. SDS 1, event marker 2



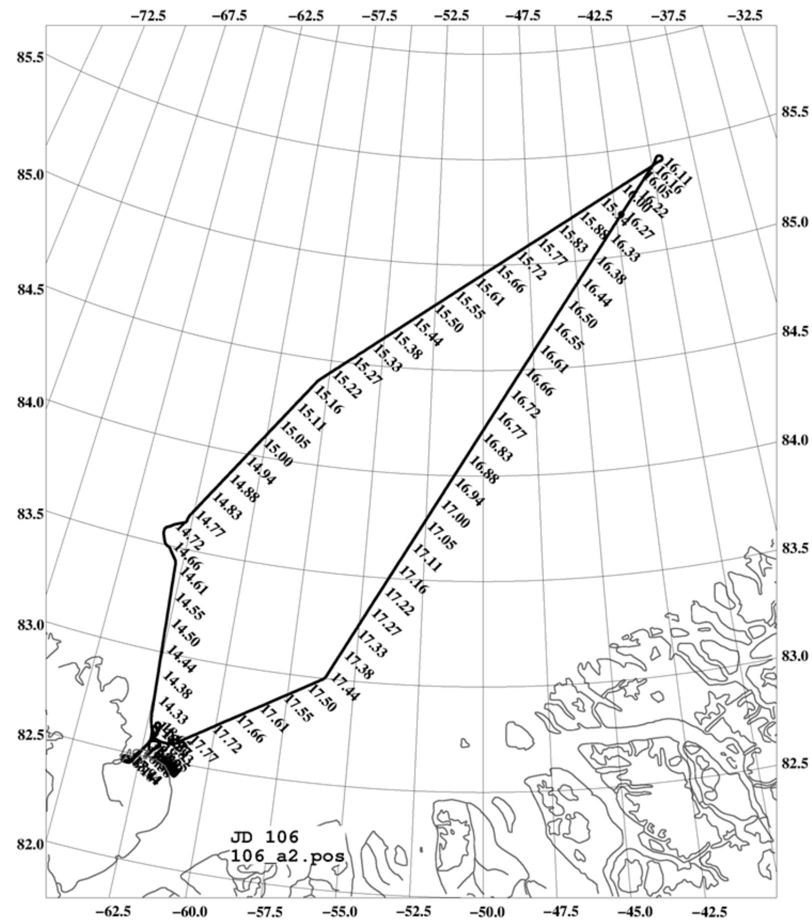
DOY 106, 16-04-2011: YLT-D3-D2-S2-6xFICE-YLT

1347 Startup system
140100 Scanner file
1409 Taxi
1411 Take off
1444 Overflight SICE, CR40-CR50, 300m
(1458) INS lost GPS signal, fixed
150000 New scanner file
1510 WP D3
160200 New scanner file
1604 fog
1605 WP D2, teardrop
170200 new scanner file
1725 WP S2
(1730) Scanner too cold :-(
1750 Validation site, FICE
1751 R1, CR1-CR2, 300m missed
1759 R2, CR2-CR1
1805 R3, CR1-CR2
1813 R4, CR2-CR1, no radar ?!?
1820 R5, CR1-CR2
1835 R6, CR2-CR1
1835 On ground, YLT

ASIRAS log

Filename: A110416_00_NN.dat
Logfile: A110416_00.log
start: 1421
calibration files:
A110416_01_1.ca2
A110416_00_1.ca1
A110416_00_2.ca1

Reflector, south insitu site
1444 R1 Webcam ok, radar wage, event marker 1, SDS 0
Overfligt fast ice
1755 R1 not hit
1800 R2 webcam ?, radar ok, event marker 2, SDS 1
1805 R3 webcam ?, radar ?, event marker 3, SDS2
1812 R4 webcam ok, missed on radar (out of altitude range)
1820 R5 webcam ok, radar ok, event marker 5, SDS 4 (event marker 4 void)
1830 R6 webcam ok, radar ok, event marker 6, SDS 5
1831 stop Asiras



DOY 107A, 17-04-2011: YLT-CRYOSAT-YLT

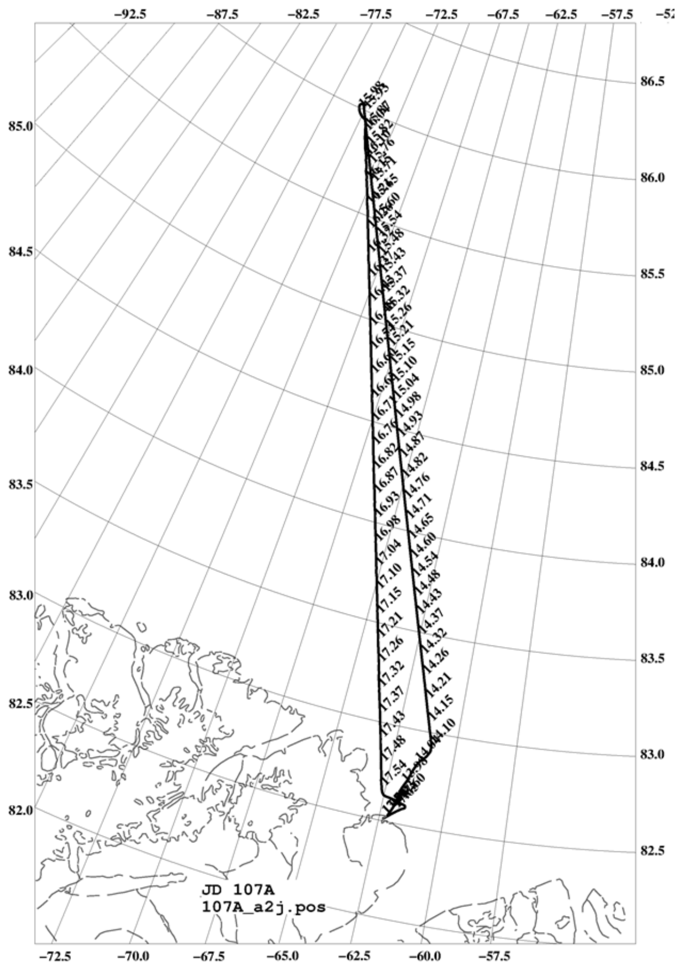
coincident flight wiht POLAR-5

1334	Ready to go
	EGI not aligned, nav-mode
	Scanner not working (38C)
1347	Polar-5 take off
1352	Taxi
1353	Take off, YLT
1405	WP01
1423	WP02
(1430)	CryoSat pass
	Laser scanner looses heat rather quickly
1502	WP03
	WP04
	WP05
1533	Patches of low fog/haze
1544	WP06
1554	Polar-5 at WP07
1557	WP07
	On route YLT, no survey
1741	On ground, YLT

ASIRAS log

times are in computer time on Asiras rack computers, see asiras log for a GPS synch signal

351(pm) asiras startup
352 start record
Filename: A110417_00.log
548 Cryosat line ends (recording continues)



DOY 107B, 17-04-2011: YLT-CALIB-2xFICE-YLT

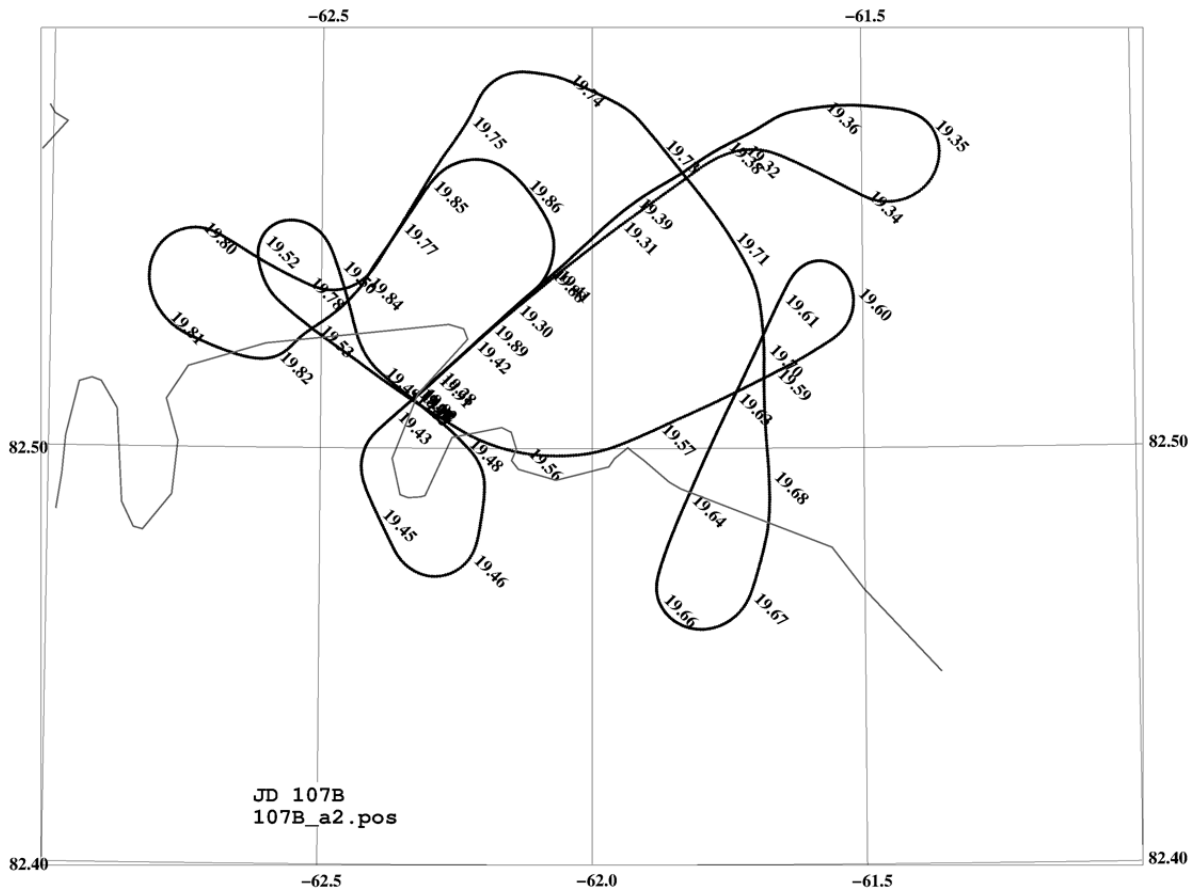
	Laser scanner .DEFAULT
	Laser scanner up and running
	EGI not aligned, nav-mode
1906	Ready to go
1915	Taxi
1916	Airborne
1924	Overflight runway, 300m
1925	Spinaker building
1928	Spinaker building
1932	Spinaker building
(1946)	In situ site FICE, 100m
1950	In situ site FICE, 100m
1954	On ground, YLT

ASIRAS log

log file: A110417_01.log
data files: A110417_01_01_1_NN.dat

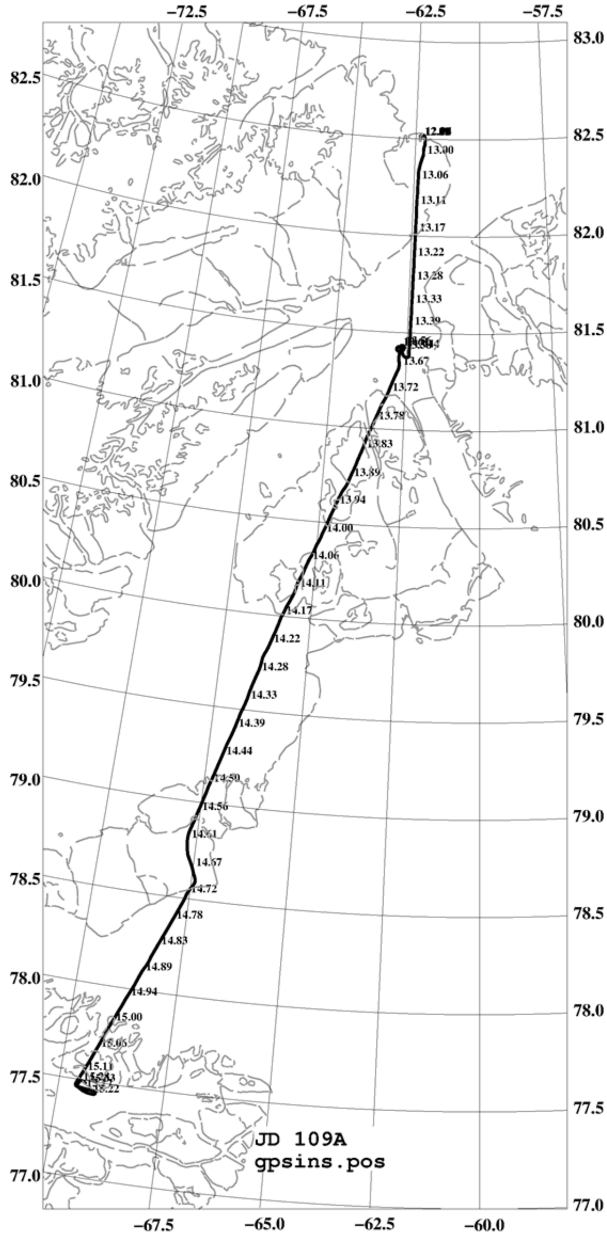
909 start
911 start recording
918 overflight runway (event 1 at end)
922 Spinaker
926 Spinaker (event 2)
928 computer freeze, restart.
933 reboot complete, file A110417_02.log

Overflight fast ice reflectors
939 miss
943 radar, wage signal.



DOY 109A, 19-04-2011: YLT-A-NAQ

1229 Engines on
1254 Taxi
1256 Take off YLT
131130 Start laser scanner logfile
1344 Poor visibility, break the line
Stop scanner logfile
Climb to 10,000 ft
1518 On ground NAQ



ASIRAS log

1500 start
1504 calibration
A110410_01_1.ca1
A110410_01_2.ca1
A110410_01_1.ca2
Filename: A110419_00.log

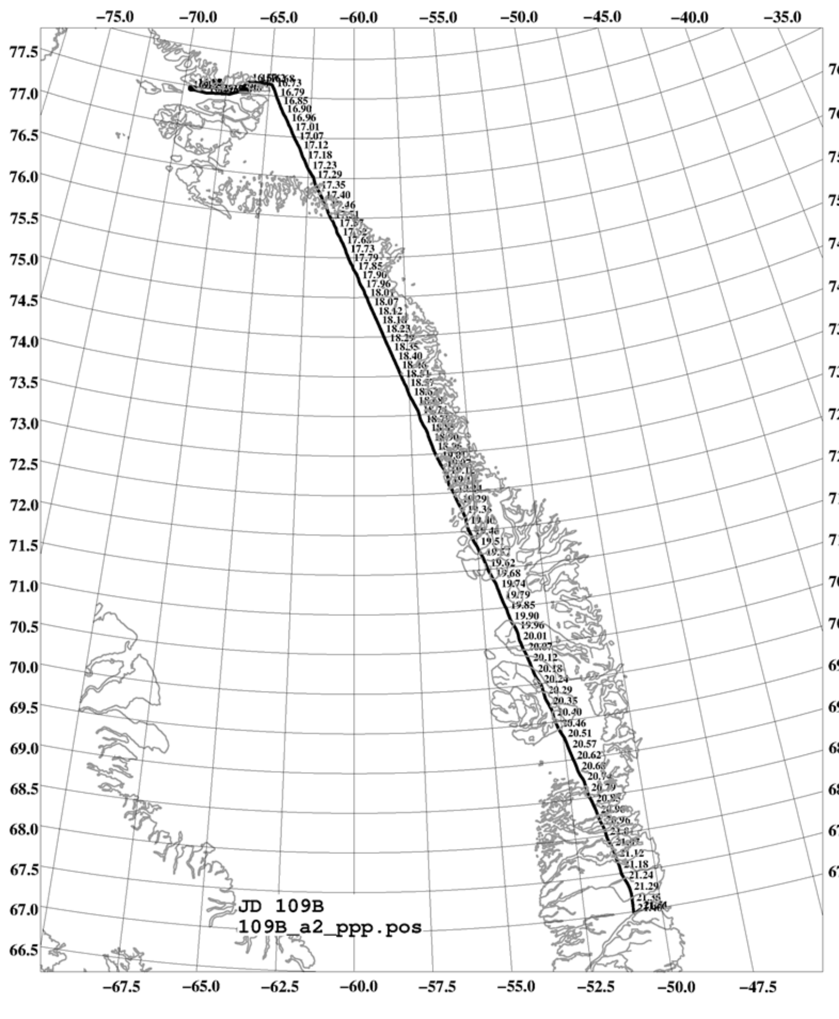
1515 computer freezes - hard reset (ctrl-alt-del has no effect)
pc1 asks for driver for DSPIO at startup
system repeadedly freezes while activating F7 (record) in asicc.exe
At Qaanaaq - working again

DOY 109B, 19-04-2011: NAQ-NAQ8-NAQ1-SFJ

1540	Ready to go
160400	New scanner file
1604	Taxi
1607	Take off NAQ
	Change camera settings
1615	NAQ8
	NAQ7
1624	NAQ5
1628	NAQ4
1632	NAQ2
1639	NAQ1
164300	New scanner file, GrIs
172900	New scanner file, sea ice
1735	Fast ice 100%
	Many icebergs and bergy bits
1752	Newly formed ridges
1758	Large areas of thin ice, grey-white
183000	New scanner file, 173000.LOG
1854	Icebergs and bergy bits
1859	Open water
1902	Low clouds
1903	Stop scanner file, climb to 2,300m
1931	Lost GPS signal INS for a few sec
2127	On ground SFJ

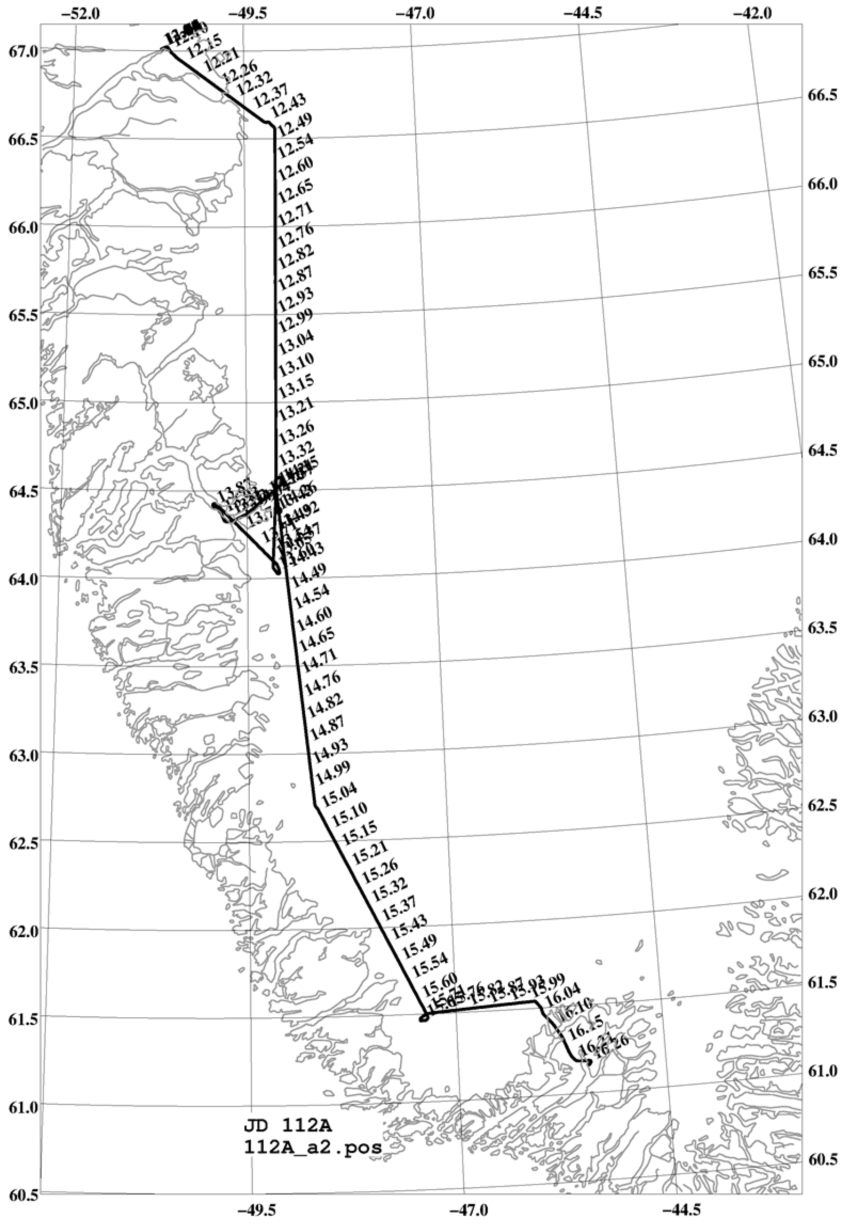
ASIRAS log

1807 start A110419_04.log
_1_NN.dat
1810 restart - hardware malfunction - blue screen of death)
1813 restart A110419_04.log - normal function
1842 pc crash while logging data - seems to happen when altitude gets out of range window.
1936 (switching cables) LAM mode running on PC2.
file: A110419_pc2_00.log
2100(ca) stop



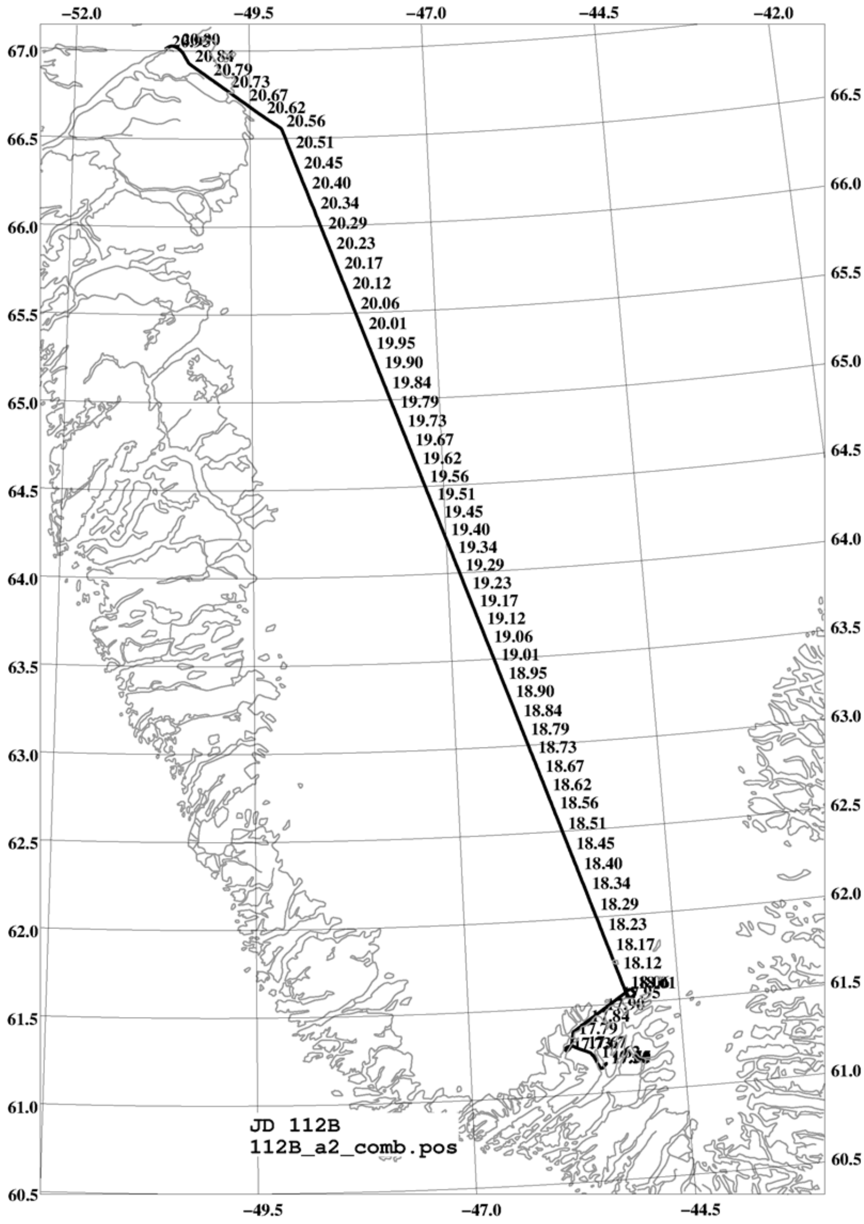
DOY 112A, 22-04-2011: SFJ-PROMICE-GCRC-UAK-SFJ

1119	Startup system
1152	Engine on
115430	Start logging scanner file
1159	Taxi
1203	Take off, SFJ
1223	INS lost GPS signal
1224	INS OK
122800	New scanner file
	SOWE1
1321	SOUT8
1333	KANS4, teardrop
133430	New scanner file
1338	KANS4
1348	KANS2
1351	KANS3
1357	KANS2
1400	KANS1
1407	SOUT8, teardrop
140930	New scanner file
1411	SOUT8
1501	SOUT7
150300	New scanner file
1537	SOUT6, teardrop
1600	SOUT9
1602	Stop survey
(1619)	On ground, UAK



DOY 112B, 22-04-2011: SFJ-PROMICE-GCRC-UAK-SFJ

1726	Ready to go
1729	Taxi
1733	Take off, UAK
173500	New scanner file
174230	New scanner file
1744	NARG3
	NARG2
	NARG1
2056	On ground, SFJ

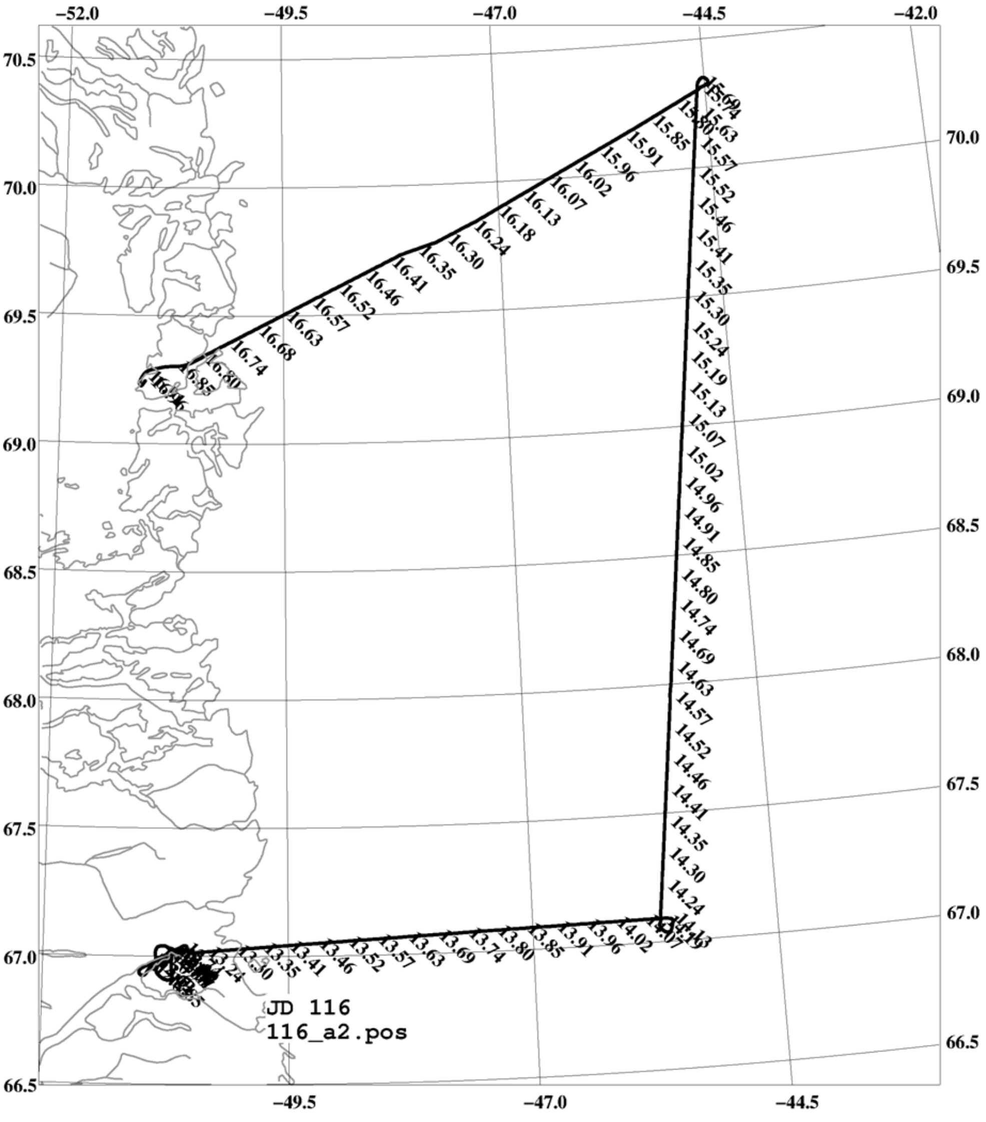


DOY 116, 26-04-2011: SFJ-CAL-CRYOSAT-T12-T1-JAV

1234	Take off
123600	Scanner file
1240	INS lost GPS signal
1245	Laser scanner fail
	INS GPS signal ok
124630	Scanner start logfile
	calibration flight SFJ
1310	calibration flight ended
131300	New scanner file
1314	webcam turned off
1406	PT1, teardrop
140900	New scanner file
150430	New scanner file
1539	PT2, teardrop
154130	New scanner file
1552	T12
1612	T5
1618	T3
1622	T1
1645	Glacier front
1647	Scanner stopped
1657	On ground JAV

ASIRAS log

1323	startup ASIRAS
1327	start record LAM
1411	on CryoSat track
1538	end CryoSat track
1543	on EGIG line
1625	turn off ASIRAS

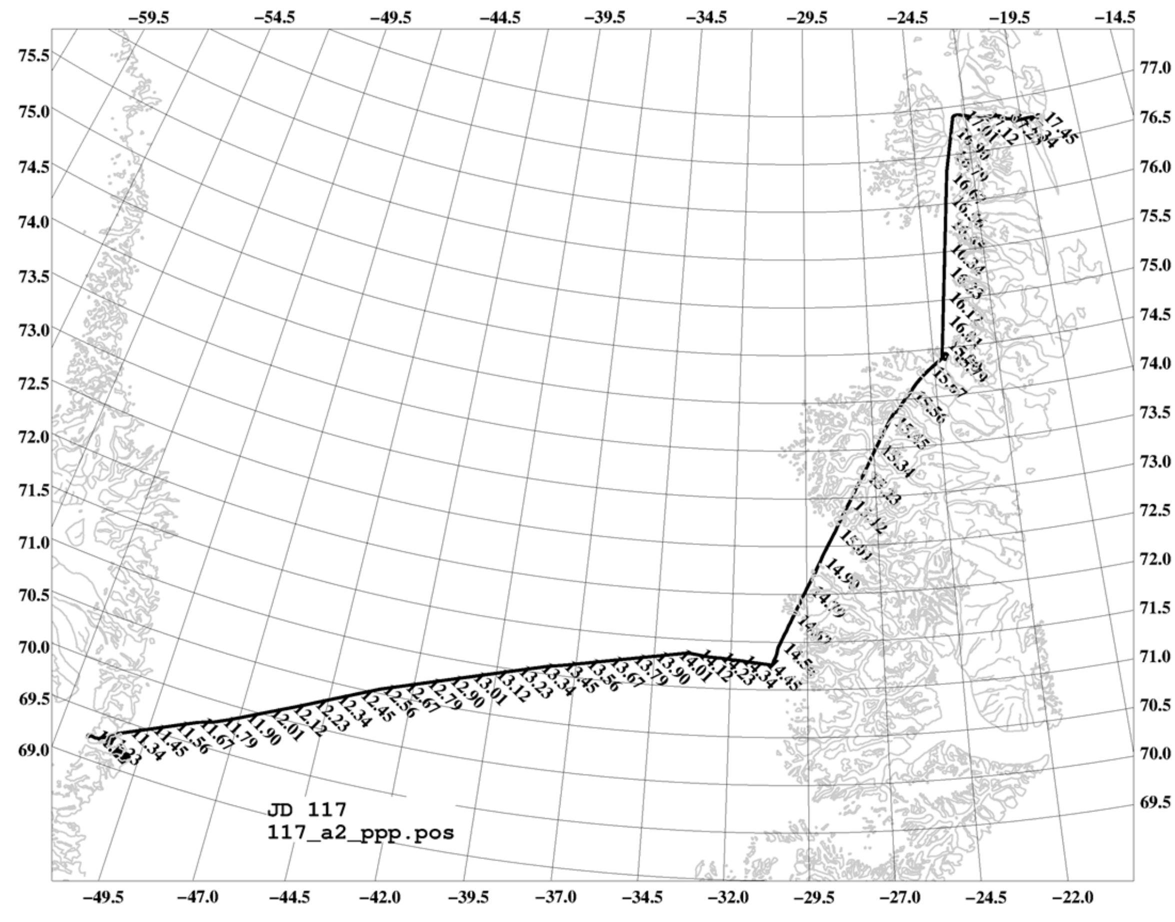


DOY 117, 27-04-2011:JAV-EGIG-DMH

1105 Taxi
1108 Take off JAV
111230 Scanner start logfile
1141 T1
1145 T3
1150 T5
120000 New scanner file
1210 T12
1234 T21
1254 INS program stopped
reset INS data cable
125715 New INS file
130000 New scanner file
1323 T41
1329 EG5
1401 Low clouds, looses laser signal
1404 EG6
Poor visibility, stop survey
.TEMP=26
1435 Heading Danmarkshavn, poor visibility
CNP
154530 New scanner file
WP B1
1641 WP B2
(1744) On ground DMH

ASIRAS log

1120 startup system
1123 CALIB 1 failed because of PC1
1129 startup ASIRAS PC2
start logging A110427_00.log
data A110427_00_2_00.dat
1406 logging stopped

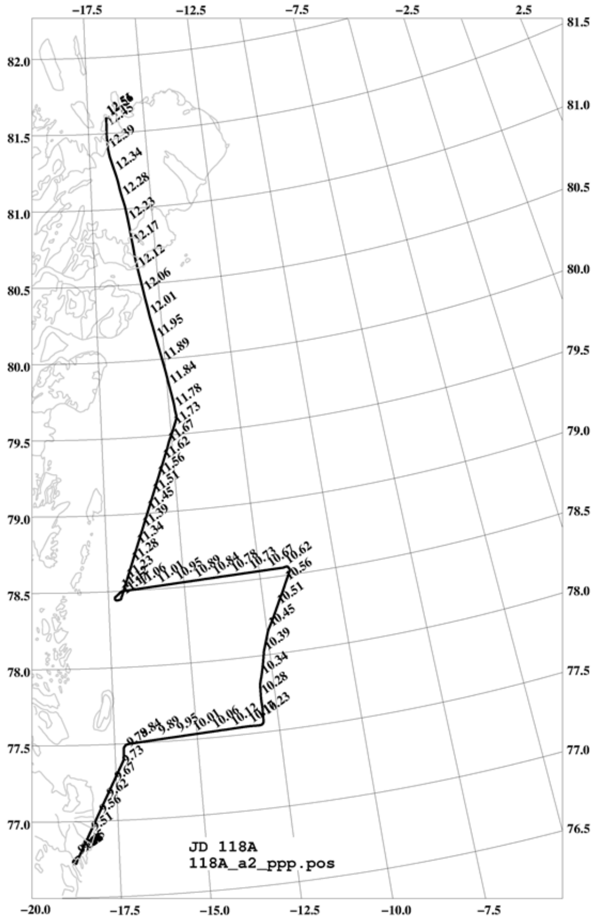


DOY 118A, 28-04-2011: DMH-RD-NRD

0922 Take off DMH
092515 Scanner logfile
0949 K17
0951 Camcorder setup looking out through starboard front window
1001 Fog
1006 Climb to 500m
1007 Stop scanner file
1012 Break the line K17-K18
Continue due north to line K19-K20
INS lost GPS signal
climb to 1200m
103430 New scanner file
Still clouds
1036 Webcam camcorder on
1038 On the line K19-K20
Still too many low clouds for laser scanner
1040 few low clouds
1044 Huge area of thin ice (grey/white)
1046 Area of low clouds/fog
1049 Clear sky
area of "small" icebergs (>20), flat, frozen into the sea ice
1052 camcorder, icebergs
Fast ice
1058 Image 650 HSK Sony camera
1103 No icebergs, fast ice
1106 K20, teardrop
1117 Area of thin low clouds
-1119
1124 Change webcam settings to light
1131 Low thin clouds/fog
1132 Laser scanner lost signal
1134 Stop camcorder and webcam
1135 Stop laser scanner logfile
1136 Climb to get a better view of the clouds
1140 Break survey
1229 On ground NRD

ASIRAS log

1003 start up system, ASIRAS PC2
1005 start logging A110428_00.log
A110428_00_2_00.dat
1018 recording stopped, due to changed plans
1036 start logging again A110428_01.log
A110428_01_2_00.dat
1135 recording stopped - clouds
1143 turn off ASIRAS

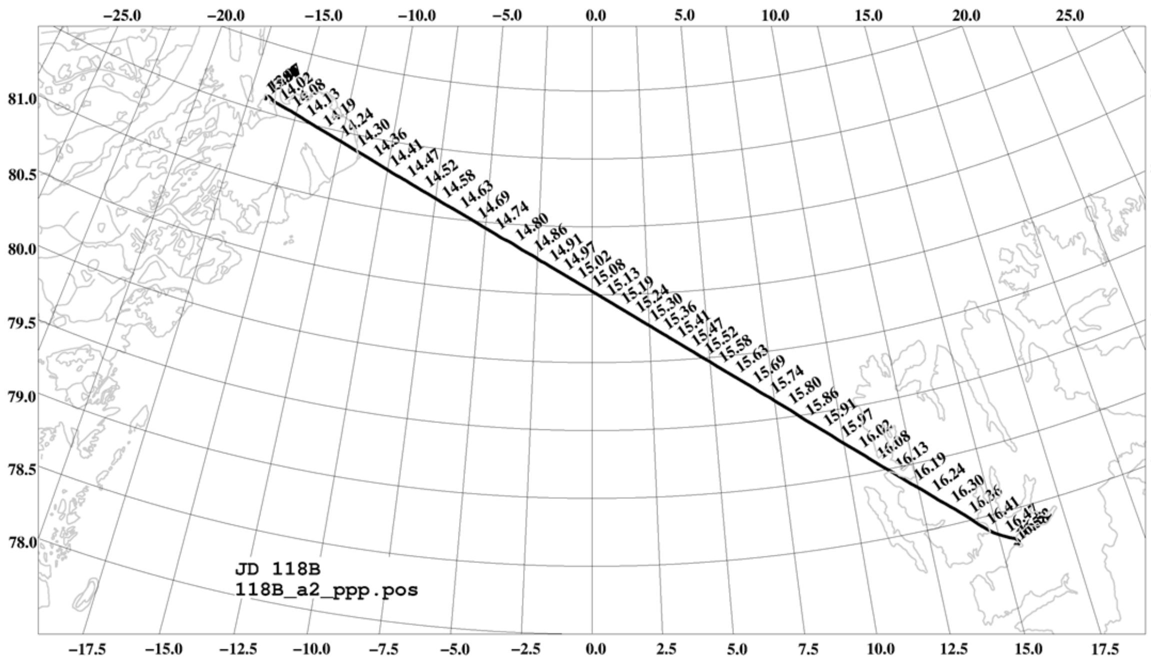


DOY 118B, 28-04-2011: NRD-LYR

1354	Taxi
1356	Take off NRD
145700	Scanner logfile
~1500	Start webcam+camcorder
1517	Change tape in camcorder
~1530	Scanner stopped
	Webcam stopped
	No more ice
	On ground LYR

ASIRAS log

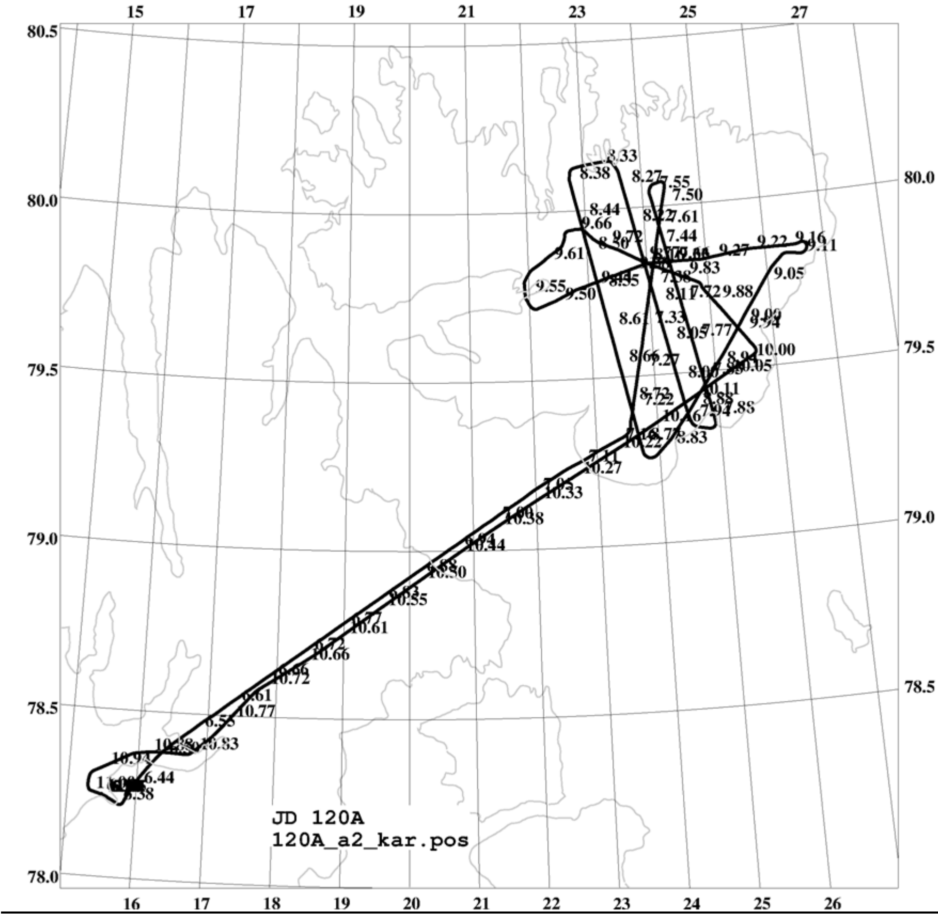
1003 start-up system, ASIRAS PC2
1005 start logging A110428_00.log
A110428_00_2_00.dat
1018 recording stopped, due to changed plans
1036 start logging again A110428_01.log
A110428_01_2_00.dat
1135 recording stopped - clouds
1143 turn off ASIRAS



DOY 120A, 30-04-2011: LYR-AUSTFONNA-LYR

0554	Startup system
0610	Ready to go
0614	Taxi
0620	Take off LYR
070800	Scanner logfile
0711	WP 4-11
0716	INS lost GPS signal
0718	INS GPS signal ok
0719	INS lost GPS signal
0721	INS ok
0722	CR2
0727	CR1, visual webcam
0729	End of line, WP 4-1
0734	Beginning of line 797
0736	CR1, visual webcam
0751	End of line 797, WP 7-1
075300	New scanner file
	A bit of fog at end of line
0806	Change webcam parameters to light
0807	CR2
0809	CR3
0816	End of line CR0405, WP CR0405_8
0822	Beginning of line CR0605
0832	CR4 visual on webcam
0847	End of line CR0605, WP CR0605_0
	CR0506_0 to SV7, survey on the route
084900	New scanner file
0910	Beginning of line, WP SV7
(0926)	CR4
	CR5 ?!?
0930	End of line, WP Eton1
093300	New scanner file
0940	Beginning of line, WP NV1
0951	A little bit off track
0958	End of line, WP NV11
1101	On ground LYR

ASIRAS log
0640 ca12 pc2 ok
0608 start record A110430_01.log
CR's marked as "events" in file, approx. overflights
0955 cal2 pc2
1000 turn off system

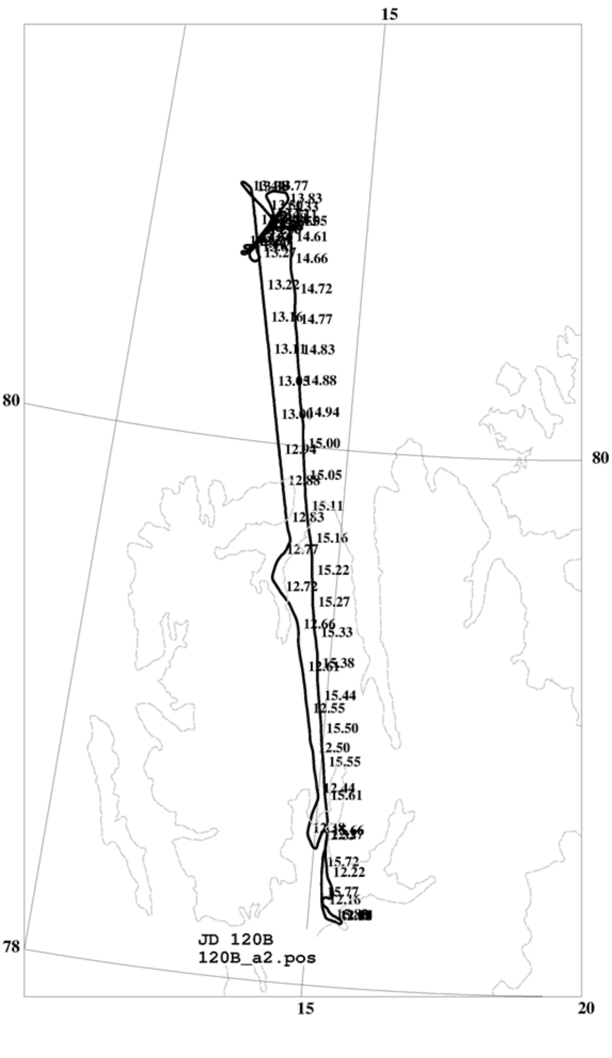


DOY 120B, 30-04-2011: LYR-RVLANCE-LYR

1205 Take off LYR
125330 Scanner logfile
Start webcam
1333 R1, CR2-CR1, 300m
1341 R2, CR1-CR2, 300m
R3, CR2-CR1, 300m, CR visually to the port
The sea ice has drifted 0.6 nm to the E/NE
140200 New scanner file
R4, CR1-CR2, low level to find position
The rest of the overflights were flown visually
1409 R5, CR2-CR1, 300m, CR1 visually webcam
1415 R6, CR1-CR2, 300m, CR1 visually webcam
1423 R7, CR2-CR1, 300m, CR1 visually webcam
R8, CR1-CR2, 300m, reflector visible in ASIRAS :-)
1432 Stop survey
On route LYR
1550 On ground, LYR

ASIRAS log

1250 turn on system
cal2 pc2 LAM
start logging A110430_02.log
A110430_02_2_00.dat
1430 stop logging
cal2 pc2 LAM
1433 shut down system



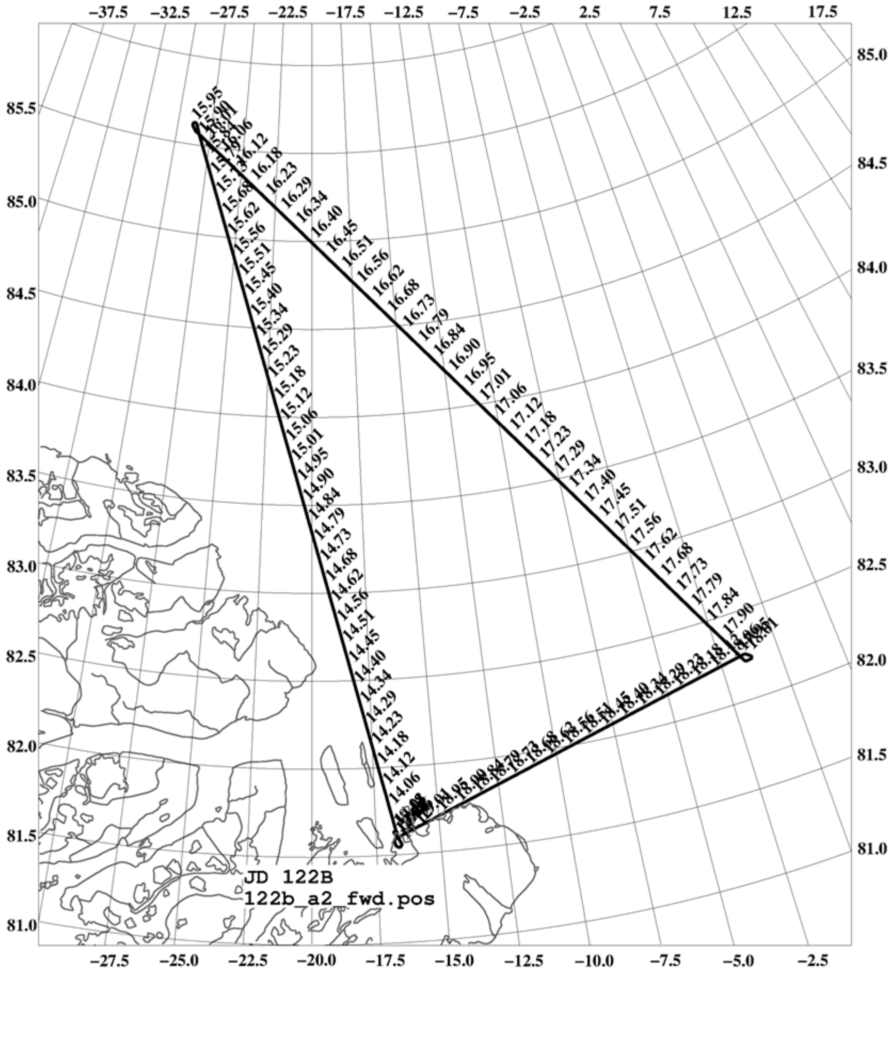
DOY 122B, 02-05-2011: NRD-F-NRD

1358 Take off NRD
140100 Laser scanner logfile
1426 Open water, new ice
1429 Change webcam setting
150000 New scanner file
Loads of open water leads
155630 New scanner file
1556 WP F2, teardrop
165500 New scanner file
1736
-1738 Patches of low clouds/fog
1756 WP F1, teardrop
175830 New scanner file
1801 Low thin clouds < 300m
1804
-1806 Laser scanner loss of signal now and then due to low clouds
1808 Laser scanner loss of signal now and then due to low clouds
1814 Laser scanner loss of signal now and then due to low clouds
1820 No more low clouds
1856 Break the line, stop survey
185700 New scanner file for calibration of building
1904 1st overflight
1908 2nd overflight
1912 On ground NRD

ASIRAS log

1552 system start + calibration
1554 start logging
2101 stop logging, shutdown

Note, part of the backup files for this day are on disks 3A/3B, while most are
on disks 2A/2B

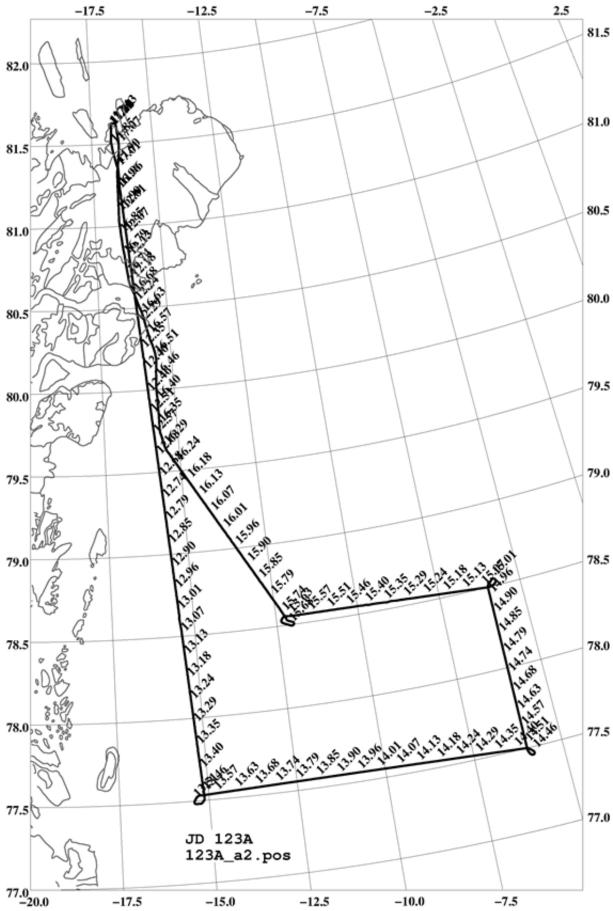


DOY 123A, 03-05-2011: NRD-RD-NRD

1146 Take off NRD
122000 Scanner logfile
1221 webcam on
1226 Camcorder on
Fast ice
1229 New record camcorder
1240 Area of icebergs in the fast ice, tabular
1308 Edge of fast ice
No icebergs, area of FYI many leads open and thin ice
1311 area of FYI/MYI and refrozen leads of grey/white ice, no icebergs
1316 Change webcam settings
Rubble fields
1319 Huge leads open and thin grey/white ice
1327 Crossing line K17-K18
132900 New scanner file
1332 On line K17-K18
1343 Area of larger floes less leads, higher ice concentration
1350 Large open leads
1356 Smaller floes
1358 Change camcorder tape
1406 Large floes of high concentration
1424 Small floes
1425 WP K18142800 New scanner file
1430 Large floes
1458 WP K19, teardrop
1508 Sea ice of high concentration
1537 Break the line K18-K19
153830 New scanner file
1544 Camcorder new tape
1546 Icebergs to the left
1548 Fast ice
1600 Icebergs to the left, limit
1606 Area of many icebergs (HSK sony 693-696)
1612 WP21
1617 Stop survey
1709 On ground NRD

ASIRAS log

1340 start. [Changing cables on radar system to enable SARIN mode from PC2]
successful SARIN calibration, LAM calibration
1342-Successful SARIN test run (too low for measurements, but data is received)
1404 SARIN working
1413 Start measurements file A110503_06 (previous files from this day, A110503_0N, N<6, are tests and were deleted)
1810 stop log

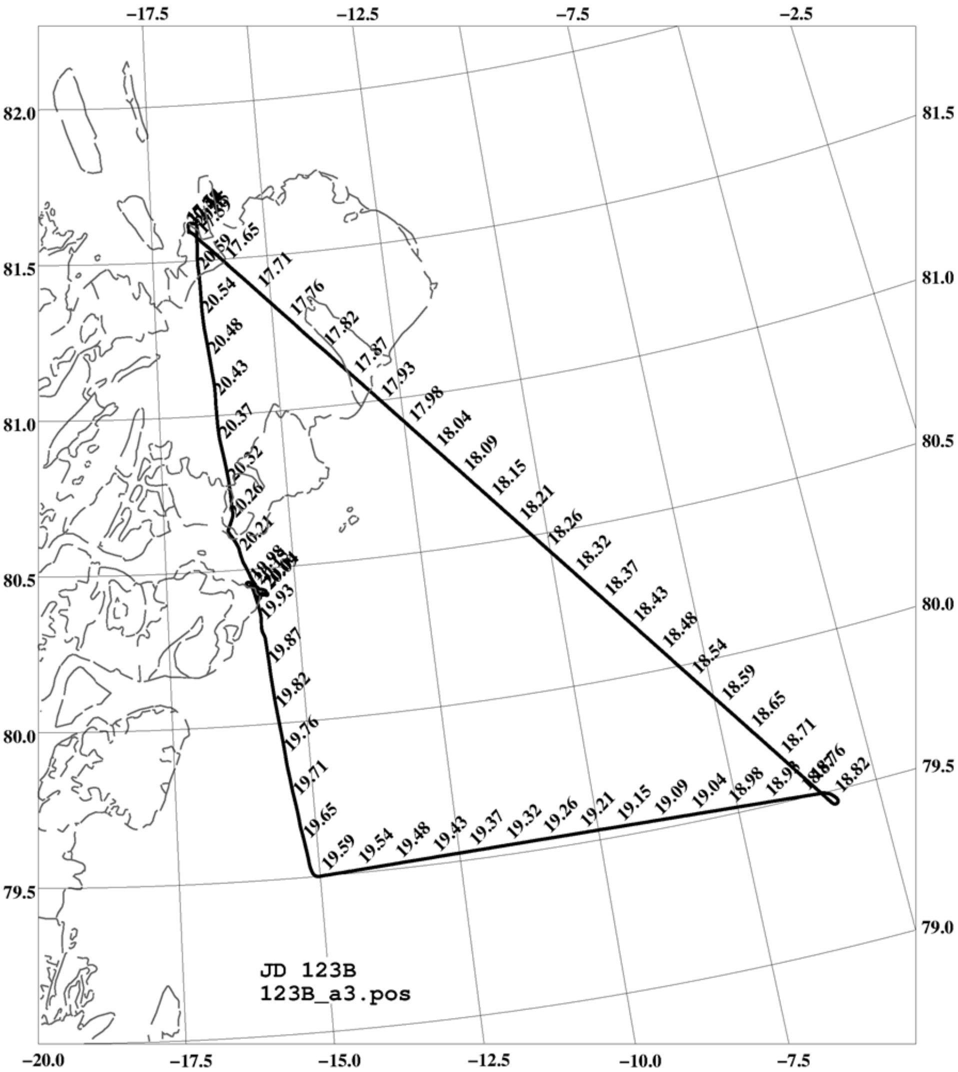


DOY 123B, 03-05-2011: NRD-RD-NRD

1729	Taxi
1733	Take off NRD
175000	Scanner logfile
1752	Webcam on
1753	Camcorder on
175330	New scanner file
1755	Few icebergs, Tabular
1804	Rubble fields, deformed ice
1846	WP K22, teardrop
184930	New scanner file
1854	Camcorder new tape
1903	1 single iceberg to the left
1911	3 icebergs to the left
1925	Fast ice, icebergs
1936	Stop survey
2042	On ground NRD

ASIRAS log

1942 calibration, start log
2128 stop log, calibration

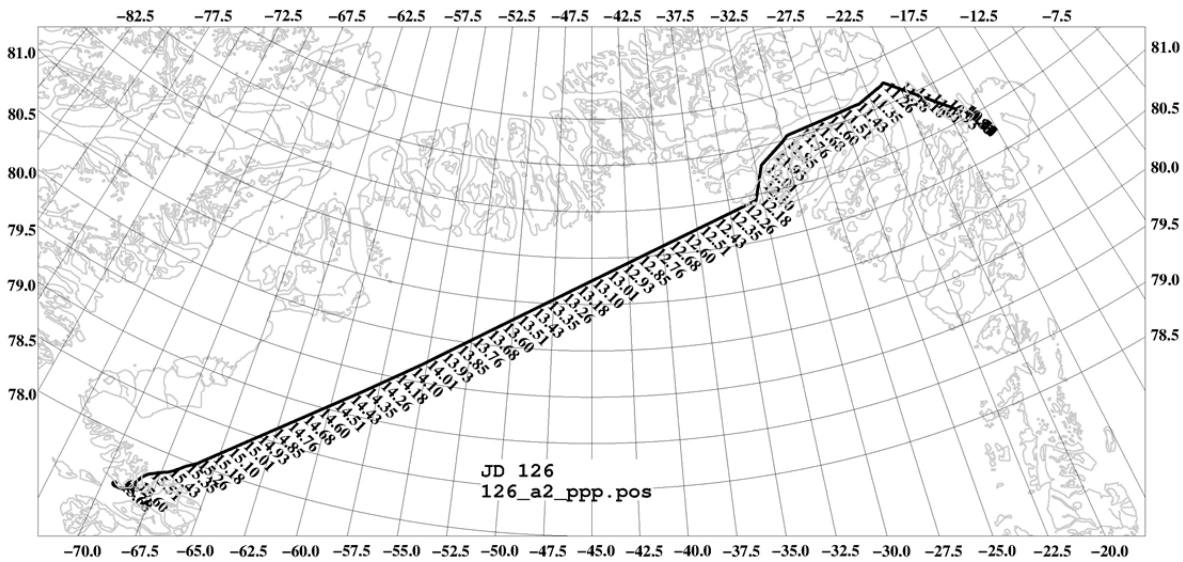


DOY 126, 06-05-2011: NRD-H-A-NAQ

1041	Engine on
1047	Taxi
	INS lost signal
1049	Take off NRD
105530	Scanner logfile
1058	INS ok, loose connection
105900	New INS file
1113	H1
1123	H2
1135	H3
1147	H4
1159	H5
120030	New scanner file
1204	Glacier front
1210	H6
130100	New scanner file
1400	WP A3
140130	New scanner file
1419	WP A2
150130	New scanner file
1514	WP A1
	Break the survey due to clouds
1544	On ground NAQ

ASIRAS log

1244 start system + calibration
1247 start log
1706 stop log, calibration [shutdown]

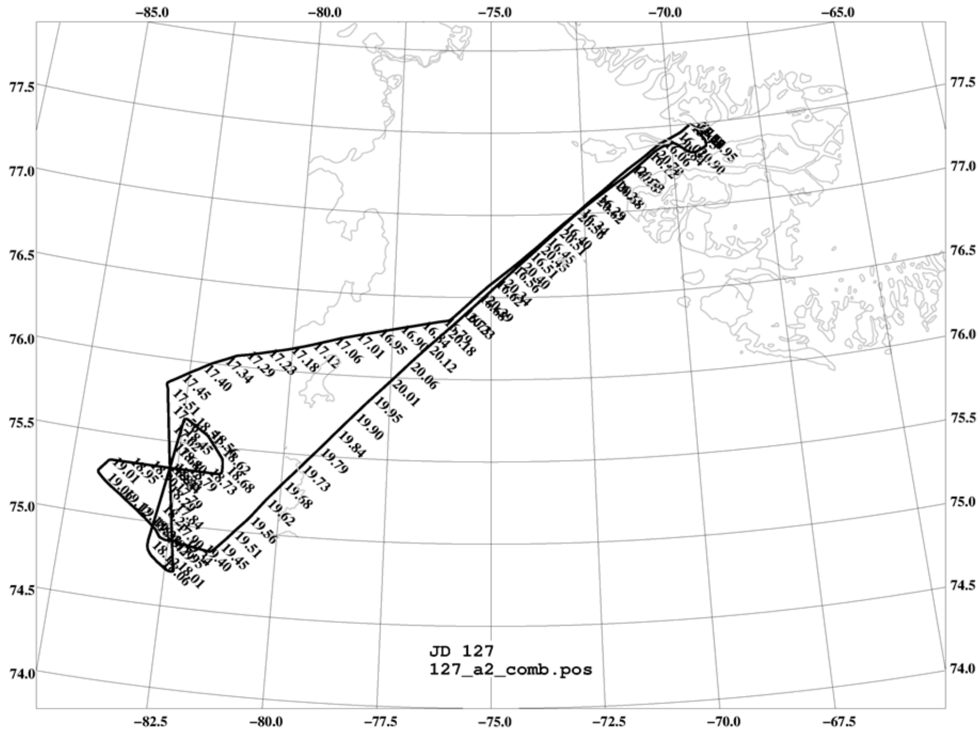


DOY 127, 07-05-2011: NAQ-DEVON-NAQ

1553 Taxi
1555 Take off NAQ
1728 On line CRYOSAT_MAY1, WP 56
173000 Scanner log file
1735 INS no GPS signal
Something wrong with front antenna splitter ?!?
No satellites measured by either AIR1 or AIR3
1742 CR_MAY1, ASIRAS OK
1744 CR_SUMMIT, ASIRAS OK
INS OK
1800 Break the line CRYOSAT_MAY1
180330 New scanner file
1808 Begin line 623, WP S4_1000M_A
1820 CR_SUMMIT
1828 End of line 623, WP 623_1
183800 New scanner file
1842 On line 450, WP 450_1
1849 CR_SUMMIT
1858 End of line 450, WP 450_9
1901 Stop scanner
190730 New scanner file
1917 Begin line SOUTHEAST1, WP SE1_3
1920 Thin clouds
1924 WP SE1_11, break the line due to clouds
Stop survey, en route NAQ
2102 On ground NAQ

ASIRAS log

1807 start, calibration and test-run (file #1 from this day void)
1918 start log
1934 reflector, weak signal visible, SDS 0, event 1
1935 reflector, signal visible, SDS 1, event 2
2012 reflector, signal visible, SDS 2 event 3
2041 reflector, signal visible, SDS 3, event 3
2118 stop log, calibration



DOY 128, 08-05-2011: NAQ-RD-JAV

1345	Take off NAQ
143000	New scanner file
1442	Change webcam parameters to grl.ini
1453	EGI stopped working, green button off
1502	WP K10
1527	Camcorder change tape
152930	New scanner file
1534	Fog
1539-41	Fog
1544	Stop camcorder
1544-49	Fog
1553	WP K9
1558-	
1600	Fog
1604-10	Fog
1622	Start camcorder
1627	End of line K9-K8
163030	New scanner file
1632	WP K8
1639	Stop survey due to fog
1922	On ground JAV

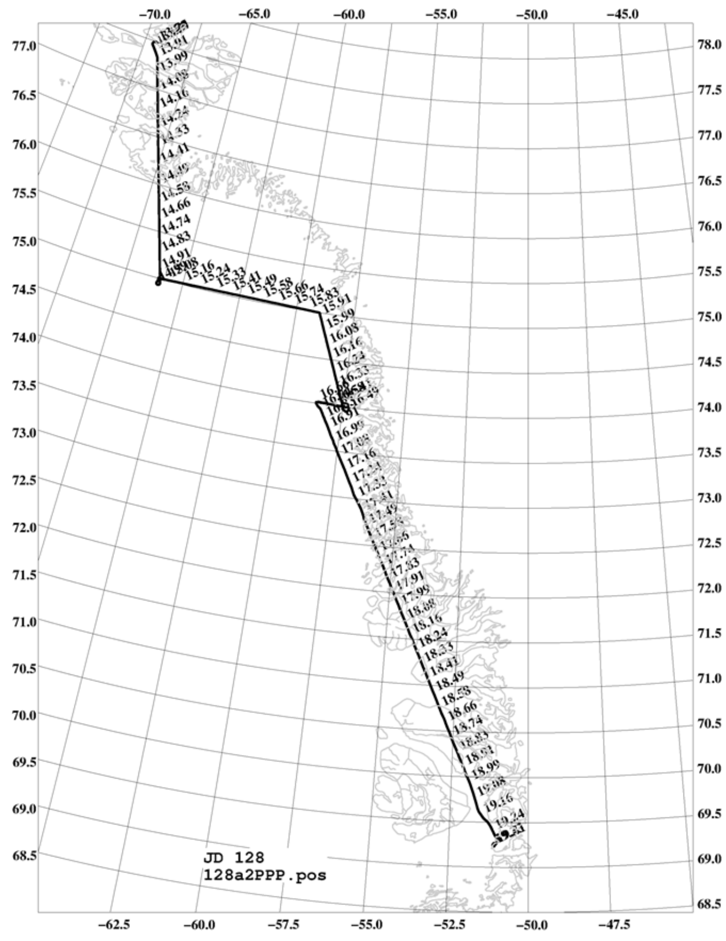
ASIRAS log

1545 start system, calibration
1620 start logging
1831 stop logging due to fog, calibration.

Calibration flight, runway Ilulissat

2057 startup + calibration
2108 start log
2112 stop log
calibration measurement was unsuccessful due to too low altitude

last file, A110508_02_2_00.dat resulted from a test-run for TV without the
radar on, therefore empty.

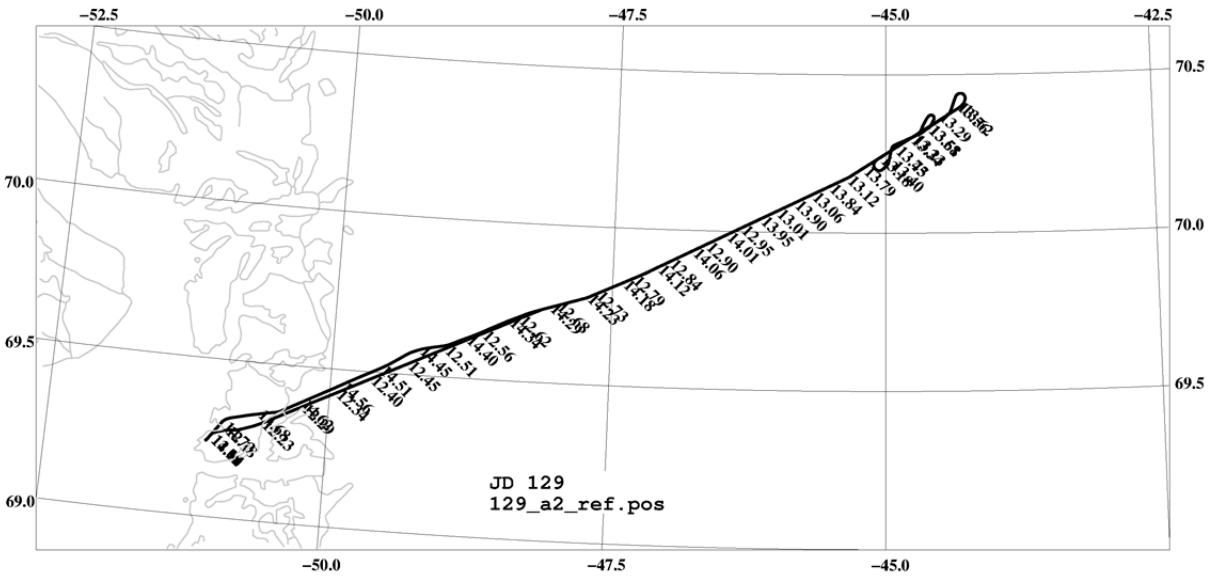


DOY 129, 09-05-2011: JAV-EGIG-JAV

1207 Taxi
1208 Take off JAV
1228 INS GPS signal lost, and fixed
123800 New scanner file
1239 T1
1243 T3
1248 T5
1307 T12
~1313 R1, CR at T15, 300m, LAM, ASIRAS OK
R2, CR at T15, 300m, LAM
~1328 R3, CR at T15, 300m, LAM, ASIRAS OK
Stop laser scanner
Climb to 1200m above surface to survey in High Altitude Mode
1342 R4, CR at T15, 1200m, HAM, ASIRAS OK
1347 T12
1408 T5
1413 T3
1417 T1
1446 On ground JAV

ASIRAS log

1403 start system, calibration. File #1 is system check.
1413 start logging
1505 reflector, signal visible, SDS 0, event 1
1510 reflector, no signal visible, SDS 1
1520 reflector, signal visible, SDS 2 event 2
1523 stop log (LAM) start log (SARIN)
1533(ca) reflector overflight, signal visible, ca 1 minute before event marker 1
1609 stop log, calibration (LAM+SARIN)



2 APPENDIX Coordinates of GPS base stations

Date	DOY	Reference	Antenna Height	Latitude	Longitude	Height (m)
10-04-2011	100	SFJ	0.000	67 00 37.39269	-50 41 34.19071	68.680
		kely1000	0.076	66 59 14.70671	-50 56 41.41990	229.807
14-04-2011	104	YLT1	0.000	82 30 47.01193	-62 19 49.89388	50.704
		YLT2	0.000	82 30 38.91694	-62 19 18.57099	46.235
15-04-2011	105A	YLT1	0.000	82 30 47.61472	-62 19 54.39108	50.714
		YLT2	0.000	82 30 38.91650	-62 19 18.56503	46.235
15-04-2011	105B	YLT1	0.000	82 30 47.61472	-62 19 54.39108	50.714
		YLT2	0.000	82 30 38.91650	-62 19 18.56503	46.235
16-04-2011	106	YLT1	0.000	82 30 47.60475	-62 19 54.32287	50.722
		YLT2	0.000	82 30 38.91608	-62 19 18.56538	46.228
17-04-2011	107A	YLT2	0.000	82 30 38.91615	-62 19 18.56591	46.232
17-04-2011	107B	YLT2	0.000	82 30 38.91615	-62 19 18.56591	46.232
19-04-2011	109A	Kmor1090	0.000	81 15 09.72000	-63 31 38.28000	196.001
22-04-2011	112A	SFJ1	0.000	67 00 21.64321	-50 42 09.72360	71.855
		SFJ2	0.000	67 00 37.53779	-50 41 33.80044	68.023
		Senu1120	0.000	61 04 10.56000	-47 08 28.68000	666.200
		Nnvn1120	0.000	61 37 54.84000	-44 54 03.96000	2134.000
22-04-2011	112B	SFJ1	0.000	67 00 21.64321	-50 42 09.72360	71.855
		SFJ2	0.000	67 00 37.53779	-50 41 33.80044	68.023
		Nnvn1120	0.000	61 37 54.84000	-44 54 03.96000	2134.000
26-04-2011	116	Kaga1160	0.000	69 13 20.28248	-49 48 52.65490	149.767
		Kely1160	0.076	66 59 14.70671	-50 56 41.41990	229.807
30-04-2011	120A	LYR1	0.000	78 14 45.87456	15 30 14.45138	53.670
		LYR2	0.000	78 14 45.89080	15 30 14.20151	53.567
30-04-2011	120B	LYR1	0.000	78 14 45.87387	15 30 14.45288	53.640
		LYR2	0.000	78 14 45.85892	15 30 14.38940	53.823
02-05-2011	122B	NRD1	0.000	81 35 46.50376	-16 39 27.59649	61.839
		NRD2	0.076	81 35 48.24781	-16 39 51.75669	61.832
03-05-2011	123A	NRD1	0.000	81 35 46.51359	-16 39 27.59678	61.760
		NRD2	0.000	81 35 48.24787	-16 39 51.76191	61.836
03-05-2011	123B	NRD1	0.000	81 35 46.51359	-16 39 27.59678	61.760
		NRD2	0.000	81 35 48.24787	-16 39 51.76191	61.836
07-05-2011	127	NAQ1	0.000	77 29 12.25410	-69 22 47.02493	27.610
		NAQ2	0.000	77 29 08.64691	-69 22 34.63500	27.729
		Thu21270	0.100	76 32 13.37129	-68 49 30.11034	36.178
09-05-2011	129	JAV1	0.000	69 14 30.53548	-51 03 43.84948	55.351
		JAV2	0.000	69 14 31.04265	-51 03 45.02257	57.179
		Kaga1290	0.000	69 13 20.28248	-49 48 52.65490	149.767

3 APPENDIX ESA File name convention ESA data format

In general the filename contains a shortcut for the instrument and the start and stop time of the data file.

ASIRAS:
AS30AXX_ASIWL1BNNNN_SSSSSSSSSSSSSSS_PPPPPPPPPPPPPPP_0001.DBL

AS30AXX	ASIRAS (AS30), AXX number of data log
ASIWL1BNNNN	Level 1B data (L1B) processor version (NNNN)
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPPPPPPPPPPP	Stop time given as YYYYMMDDTHHMMSS

GPS
GPS_ANT_VER_SSSSSSSSSSSSSSS-PPPPPP_0001.DAT

ANT	GPS antenna R for rear, and F for front
VER	Version
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

Inertial Navigation System (INS)
INS_ SSSSSSSSSSSSSSS-PPPPPP_0001.DAT

SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

Airborne laser scanner (ALS) full resolution
ALS_L1B_ SSSSSSSSSSSSSSS-PPPPPP.DAT

L1B	Level 1B data
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

Airborne laser scanner (ALS) 5mx5m resolution
ALS_L1B_ D2_SSSSSSSSSSSSSSS-PPPPPP.DAT

L1B	Level 1B data
D2	Coarse resolution
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPP	Stop time given as HHMMSS

AEM data files
HEM_CMPID_SSSSSSSSSSSSSSS_PPPPPPPPPPPPPPP.dat

CMPID	Contains campaign name (3 letters + 2 digits of year), The id for the CryoVEx 2011 field campaign is given by CRV11.
SSSSSSSSSSSSSSS	Start time given as YYYYMMDDTHHMMSS
PPPPPPPPPPPPPPP	Stop time given as YYYYMMDDTHHMMSS

4 APPENDIX ESA data format

The following appendix has been adapted from Stenseng et al (2007). The format description for core products is taken from the "ASIRAS, product Description, Issue: 2.6.1" by Cullen (2010) and the users should refer to this document for detailed information. The definition of the types used in the binary files can be found in Table 15.

Table 15: Defintion of binary types used in the description of the file format

Type	Description	Size [Bytes]
uc	Unsigned character	1
sc	Signed character	1
us	Unsigned short integer	2
ss	Signed short integer	2
ul	Unsigned long integer	4
sl	Signed long integer	4
ull	Unsigned long long integer	8
sll	Signed long long integer	8
d	Double precision floating	8
f	Single precision floating	4
[n]	Array length n	

4.1 ASIRAS L1b

Processed L1b ASIRAS data is delivered in binary, big endian format as described by Cullen (2010) and Tables 16, 17 and 18.

The L1b product consists of two elements.

1. An ASCII header consisting of a main product header (MPH), a specific product header (SPH), and the data set descriptors (DSDs).
2. A binary, big endian measurement data set (MDS).

Table 16: ASIRAS main product header (MPH) format

Field #	Description	Units	Bytes	Format
Product Identification Information				
#01	PRODUCT=	keyword	8	8*uc
	quotation mark (")		1	uc
	Product File Name		62	uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc

Continued on next page

Field #	Description	Units	Bytes	Format
#02	PROC_STAGE=	keyword	11	11*uc
	Processing stage code: N = Near-Real Time T = Test O = OFF Line (Systematic) R = Reprocessing L = Long Term Archive		1	uc
	newline character	terminator	1	uc
#03	REF_DOC=	keyword	8	8*uc
	quotation mark (")		1	uc
	Reference DFCB Document describing the product		23	23*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#04	Spare		40	40*uc
	newline character	terminator	1	uc
Data Processing Information				
#05	ACQUISITION_STATION=	keyword	20	20*uc
	quotation mark (")		1	uc
	Acquisition Station ID Filled by blanks		20	Kiruna
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#06	PROC_CENTER=	keyword	12	12*uc
	quotation mark (")		1	uc
	Processing Center ID code		6	PDS
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#07	PROC_TIME=	keyword	10	10*uc
	quotation mark (")		1	uc
	Processing Time (Product Generation Time)	UTC	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#08	SOFTWARE_VER=	Keyword	13	13*uc
	quotation mark (")		1	uc
	Processor name, up to 8 characters, software version number followed by trailer blanks if any. If not used set to blanks		14	14*uc ProcessorName/VV.rr
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#09	Spare (blank characters)		40	40*uc
	newline character	terminator	1	uc

Continued on next page

Field #	Description	Units	Bytes	Format
Information on Time of Data				
#10	SENSING_START=	keyword	14	14*uc
	quotation mark (")		1	uc
	UTC start time of data sensing. This is the UTC start time of the Input Level 0 Product. If not used set to 27 blanks	UTC	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#11	SENSING_STOP=	keyword	13	13*uc
	quotation mark (")		1	uc
	UTC stop time of data sensing. This is the UTC stop time of the Input Level 0 Product. If not used set to 27 blanks	UTC	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#12	Spare (blank characters)		40	40*uc
	newline character	terminator	1	uc
Orbit Information				
#13	PHASE=	keyword	6	6*uc
	Phase Code: phase letter (A, B, \...) If not used set to X		1	uc
	newline character	terminator	1	uc
#14	CYCLE=	keyword	6	6*uc
	Cycle number. If not used set to +000		4	%+04d
	newline character	terminator	1	uc
#15	REL_ORBIT=	keyword	10	10*uc
	Relative Orbit Number at sensing start time. If not used set to +00000		6	%+06d
	newline character	terminator	1	uc
#16	ABS_ORBIT=	keyword	10	10*uc
	Absolute Orbit Number at sensing start time. If not used set to +00000		6	%+06d
	newline character	terminator	1	uc
#17	STATE_VECTOR_TIME=	keyword	18	18*uc
	quotation mark (")		1	uc
	UTC state vector time It is filled properly in case of usage of FOS Predicted Orbit information otherwise it shall be set to 27 blanks	UTC	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc

Continued on next page

Field #	Description	Units	Bytes	Format
#18	DELTA_UT1=	keyword	10	10*uc
	Universal Time Correction: DUT1 = UT1 - UTC Not used for ASIRAS. It shall be set to +.000000	s	8	%+08.6f
	<s>	units	3	3*uc
	newline character	terminator	1	uc
#19	X_POSITION=	keyword	11	11*uc
	X position in Earth Fixed Reference. If not used set to +0000000.000	m	12	%+012.3f
	<m>	units	3	3*uc
	newline character	terminator	1	uc
#20	Y_POSITION=	keyword	11	11*uc
	Y position in Earth Fixed Reference. If not used set to +0000000.000	m	12	%+012.3f
	<m>	units	3	3*uc
	newline character	terminator	1	uc
#21	Z_POSITION=	keyword	11	11*uc
	Z position in Earth Fixed Reference. If not used set to +0000000.000	m	12	%+012.3f
	<m>	units	3	3*uc
	newline character	terminator	1	uc
#22	X_VELOCITY=	keyword	11	11*uc
	X velocity in Earth Fixed Reference. If not used set to +0000.000000	m/s	12	%+012.6f
	<m/s>	units	5	5*uc
	newline character	terminator	1	uc
#23	Y_VELOCITY=	keyword	11	11*uc
	Y velocity in Earth Fixed Reference. If not used set to +0000.000000	m/s	12	%+012.6f
	<m/s>	units	5	5*uc
	newline character	terminator	1	uc
#24	Z_VELOCITY=	keyword	11	11*uc
	Z velocity in Earth Fixed Reference. If not used set to +0000.000000	m/s	12	%+012.6f
	<m/s>	units	5	5*uc
	newline character	terminator	1	uc
#25	VECTOR_SOURCE=	keyword	14	14*uc
	quotation mark (")		1	uc
	Source of Orbit State Vector Record FP = FOS predicted DN = DORIS Level 0 navigator DP = DORIS precise orbit FR = FOS Restituted DI = DORIS Preliminary		2	2*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc

Field #	Description	Units	Bytes	Format
#26	Spare (blank characters)		40	40*uc
	newline character	terminator	1	uc
	SBT to UTC conversion information			
#27	UTC_SBT_TIME=	Keyword	13	13*uc
	quotation mark (")		1	uc
	Not used and set to 27 blanks		27	27*uc
	quotation mark (")		1	uc
	newline character	Terminator	1	uc
#28	SAT_BINARY_TIME=	Keyword	16	16*uc
	Satellite Binary Time Not used for Cryosat and it shall be set to zeros		11	+0000000000
	newline character	Terminator	1	uc
#29	CLOCK_STEP =	Keyword	11	11*uc
	Clock Step Not used for Cryosat and it shall be set to zeros		11	+0000000000
	<ps>	Units	4	4*uc
	newline character	Terminator	1	uc
#30	Spare (blank characters)		32	32*uc
	newline character	Terminator	1	uc
	Leap Second Information			
#31	LEAP_UTC=	Keyword	9	9*uc
	quotation mark (")		1	uc
	UTC Time of the occurrence of the leap second. If a leap second occurred in the product window the field is set by a devoted function in the CFI EXPLORER_ORBIT library (see [EXPL_ORB-SUM] for details), otherwise it is set to 27 blanks. It corresponds to the time after the Leap Second occurrence (i.e. midnight of the day after the leap second)	UTC	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#32	LEAP_SIGN=	Keyword	10	10*uc
	Leap second sign If a leap second occurred in the product window the field is set to the expected value by a devoted function in the CFI EXPLORER_ORBIT library (see [EXPL_ORB-SUM] for details), otherwise it is set to +000.	S	4	%+04d
	newline character	terminator	1	uc

Continued on next page

Field #	Description	Units	Bytes	Format
#33	LEAP_ERR=	keyword	9	9*uc
	Leap second error flag. This field is always set to 0 considering that CRYOSAT products have true UTC times.		1	uc
	newline character	terminator	1	uc
#34	Spare (blank characters)		40	40*uc
	newline character	terminator	1	uc
Product Confidence Data Information				
#35	PRODUCT_ERR=	keyword	12	12*uc
	Product Error Flag set to 1 if errors have been reported in the product		1	uc
	newline character	terminator	1	uc
Product Size Information				
#36	TOT_SIZE=	keyword	9	9*uc
	Total size of the product	bytes	21	%+021d
	<bytes>	units	7	7*uc
	newline character	terminator	1	uc
#37	SPH_SIZE=	keyword	9	9*uc
	Length of the SPH	bytes	11	%+011d
	<bytes>	units	7	7*uc
	newline character	terminator	1	uc
#38	NUM_DSD=	keyword	8	8*uc
	Number of Data Set Descriptors, including spares and all other types of DSDs		11	%+011d
	newline character	terminator	1	uc
#39	DSD_SIZE=	keyword	9	9*uc
	Length of each DSD	bytes	11	%+011d
	<bytes>	units	7	7*uc
	newline character	terminator	1	uc
#40	NUM_DATA_SETS=	keyword	14	14*uc
	Number of attached Data Sets (note that not all the DSDs have a DS attached)		11	%+011d
	newline character	terminator	1	uc
#41	CRC=	keyword	4	4*uc
	Cyclic Redundancy Code computed as overall value of all records of the Measurement Data Set. If not computed it shall be set to -00001		6	%+06d
	newline character	terminator	1	uc
#42	Spare (blank characters)		29	29*uc
	newline character	terminator	1	uc
Total				**1247**

Table 17: ASIRAS specific product header (SPH) format

Field #	Description	Units	Bytes	Format
Product description and identification				
#1	SPH_DESCRIPTOR=	keyword	15	15*uc
	quotation mark (")		1	uc
	ASCII string describing the product Set to ASI_SAR_1B SPECIFIC HEADER		28	28*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc
Product Time information				
#2	START_RECORD_TAI_TIME=	keyword	22	22*uc
	quotation mark (")		1	uc
	TAI of the first record in the Main MDS of this product	TAI	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#3	STOP_RECORD_TAI_TIME=	keyword	21	21*uc
	quotation mark (")		1	uc
	TAI of the last record in in the Main MDS of this product	TAI	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
Product Orbit Information				
#4	ABS_ORBIT_START=	keyword	16	16*uc
	Absolute Orbit Number at Product Start Time		6	%06d
	newline character	terminator	1	uc
#5	REL_TIME_ASC_NODE_START=	Keyword	24	24*uc
	Relative time since crossing ascending node time relative to start time of data sensing	s	11	%011.6f
	<s>	units	3	3*uc
	newline character	terminator	1	uc
#6	ABS_ORBIT_STOP=	keyword	15	15*uc
	Absolute Orbit Number at Product Stop Time		6	%06d
	newline character	terminator	1	uc
#7	REL_TIME_ASC_NODE_STOP=	Keyword	23	23*uc
	Relative time since crossing ascending node time relative to stop time of data sensing	s	11	%011.6f
	<s>	units	3	3*uc
	newline character	terminator	1	uc

Continued on next page

Field #	Description	Units	Bytes	Format
#8	EQUATOR_CROSS_TIME_UTC=	Keyword	23	23*uc
	quotation mark (")		1	uc
	Time of Equator crossing at the ascending node of the sensing start time	UTC	27	dd-MMM-yyyy hh:mm:ss.uuuuuu
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#9	EQUATOR_CROSS_LONG=	Keyword	19	19*uc
	Longitude of Equator Crossing at the ascending node of the sensing start time (positive East, 0 = Greenwich) referred to WGS84	s	11	%+011d
	<10-6degE>	units	10	10*uc
	newline character	terminator	1	uc
#10	ASCENDING_FLAG=	keyword	15	15*uc
	Orbit Orientation at the sensing start A= Ascending D= Descending		1	uc
	newline character	terminator	1	uc
Product Location Information				
#11	START_LAT=	keyword	10	10*uc
	WGS84 latitude of the first record in the Main MDS (positive north)	[10-6 deg]	11	%+011d
	<10-6degN>	units	10	10*uc
	newline character	terminator	1	uc
#12	START_LONG=	keyword	11	11*uc
	WGS84 longitude of the first record in the Main MDS (positive East, 0 = Greenwich)	[10-6 deg]	11	%+011d
	<10-6degE>	units	10	10*uc
	newline character	terminator	1	uc
#13	STOP_LAT=	keyword	9	9*uc
	WGS84 latitude of the last record in the Main MDS (positive north)	[10-6 deg]	11	%+011d
	<10-6degN>	units	10	10*uc
	newline character	terminator	1	uc
#14	STOP_LONG= keyword 10 10*uc			
	WGS84 longitude of the last record in the Main MDS (positive East, 0 = Greenwich)	[10-6 deg]	11	%+011d
	<10-6degE>	units	10	10*uc
	newline character	terminator	1	uc
#15	Spare (blank characters)		50	50*uc
	newline character	terminator	1	uc

Field #	Description	Units	Bytes	Format
Level 0 Quality information				
#16	L0_PROC_FLAG=	keyword	13	13*uc
	Processing errors significance flag (1 or 0). 1 if the percentage of SIRAL packets free of processing errors is less than the acceptable threshold		1	uc
	newline character	terminator	1	uc
#17	L0_PROCESSING_QUALITY=	keyword	22	22*uc
	Percentage of quality checks successfully passed during the SP processing (max allowed +10000)	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#18	L0_PROC_THRESH=	keyword	15	15*uc
	Minimum acceptable percentage of quality threshold that must be passed during SP processing (max allowed +10000)	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#19	L0_GAPS_FLAG=	keyword	13	13*uc
	Gaps significance flag (1 or 0). 1 if gaps (either caused by extraction or alignment failures) were detected during the SP processing		1	uc
	newline character	terminator	1	uc
#20	L0_GAPS_NUM=	keyword	12	12*uc
	Number of gaps detected during the SP processing (no gaps indicated as +0000000)		8	%+08d
	newline character	terminator	1	uc
#21	Spare (blank characters)	ascii	50	50*uc
	newline character	terminator	1	uc
ASIRAS Instrument Configuration				
#22	ASI_OP_MODE=	keyword	12	12*uc
	quotation mark (")		1	uc
	ASIRAS Operative Mode: HAM LAM (strings shorter than 10 are filled in with blanks)		10	10*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc

Field #	Description	Units	Bytes	Format
#23	ASI_CONFIGURATION=	keyword	18	17*uc
	quotation mark (")		1	uc
	SIRAL Configuration: RX_1 RX_2 BOTH UNKNOWN (strings shorter than 7 are filled in with blanks)		7	7*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc
Surface Statistics				
#24	OPEN_OCEAN_PERCENT=	keyword	19	19*uc
	Percentage of records detected on open ocean or semi-enclosed seas	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#25	CLOSE_SEA_PERCENT=	keyword	18	18*uc
	Percentage of records detected on seas or inland lakes	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#26	CONTINENT_ICE_PERCENT=	keyword	22	22*uc
	Percentage of records detected on continental ice	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	Uc
#27	LAND_PERCENT Keyword 13 13*uc			
	Percentage of records detected on land	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#28	Spare (blank characters)	ascii	50	50*uc
	newline character	terminator	1	uc
Level 1 Processing information				
#29	L1B_PROD_STATUS=	keyword	16	16*uc
	Complete/Incomplete Product Completion Flag (0 or 1). 1 if the Product as a duration shorter the input Level 0		1	uc
	newline character	terminator	1	uc
#30	L1B_PROC_FLAG=	keyword	14	14*uc
	Processing errors significance flag (1 or 1 if the percentage of DSR free of processing errors is less than the acceptable threshold		1	uc
	newline character	terminator	1	uc

Field #	Description	Units	Bytes	Format
#31	L1B_PROCESSING_QUALITY=	keyword	23	23*uc
	Percentage of quality checks successfully passed during Level 1B processing (max allowed +10000)	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#32	L1B_PROC_THRESH=	keyword	16	16*uc
	Minimum acceptable percentage of quality threshold that must be passed during Level 1B processing (max allowed +10000)	[10-2%]	6	%+06d
	<10-2%>	units	7	7*uc
	newline character	terminator	1	uc
#33	Spare (blank characters)	ascii	50	50*uc
	newline character	terminator	1	uc
Total				**1112**
		DSD Section		

Table 18: ASIRAS data set descriptors (DSD) format

Field #N	Description	Units	Bytes	Format
		DSD		
#N.1	DS_vvvvvvvvvvvvvvvv	keyword	8	8*uc
	quotation mark (")		1	uc
	Name describing the Data Set		28	28*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc
#N.2	DS_TYPE=	keyword	8	8*uc
	Type of Data Set. It can be: M = Measurement R = Reference		1	uc
	newline character	terminator	1	uc
	External Product Reference			
		External Product Reference		
#N.3	FILENAME=	keyword	9	9*uc
	quotation mark (")		1	uc
	Name of the Reference File. Used if DS_TYPE is set to R. It is left trailer blanks. The file name If not used it is set to 62 blanks.		62	62*uc
	quotation mark (")		1	uc
	newline character	terminator	1	uc
	Position and site of DS			

Field #N	Description	Units	Bytes	Format
Position and size of DS				
#N.4	DS_OFFSET=	keyword	10	10*uc
	Length in bytes of MPH + SPH DS size of previous Data Set (if	bytes	21	%+021d
	<bytes>	units	7	7*uc
	newline character	terminator	1	uc
#N.5	DS_SIZE=	keyword	8	8*uc
	Length in bytes of the attached Used if DS_TYPE is set to M If not used set to 0	bytes	21	%+021d
	<bytes>	units	7	7*uc
	newline character	terminator	1	uc
	Number and length of DSRs			
Number and length of DSRs				
#N.6	NUM_DSR=	keyword	8	8*uc
	Number of Data Set Records		11	%+011d
	newline character	terminator	1	uc
#N.7	DSR_SIZE=	keyword	9	9*uc
	Length in bytes of the Data Set If not used set to +0 If variable set to -1	bytes	11	%+011d
	<bytes>	units	7	7*uc
	newline character	terminator	1	uc
#N.8	Spare	ascii	32	32*uc
	newline character	terminator	1	uc
Total				**280**

The MDS can be further divided into five parts as described below:

1. Time and Orbit Group (20 blocks per record)
2. Measurements Group (20 blocks per record)
3. Corrections Group (one block per record)(Zeroed for ASIRAS)
4. Average waveforms Group (one block per record)(Zeroed for ASIRAS)
5. Waveform Group (20 blocks per record)

Table 19: ASIRAS measurement data set (MDS) format

Identifier	Description	Units	Type	Size [Bytes]
Time & Orbit Group Repeated 20 times				
1	Days	TAI	sl	4
2	Seconds		ul	4
3	Microseconds		ul	4
4	Spare		sl	4
5	Spare		us	2

Identifier	Description	Units	Type	Size [Bytes]
6	Spare		us	2
7	Instrument Config		ul	4
8	Burst Counter		ul	4
9	Geodetic latitude of	10^{-7} Deg	sl	4
10	Longitude of ASIRAS	10^{-7} Deg	sl	4
11	WGS-84 ellipsoidal	10^{-3} m	sl	4
12	Altitude rate determined	10^{-6} m/s	sl	4
13	Velocity [x,y,z], described	10^{-3} m/s	sl	3*4
14	Real antenna beam	10^{-6} m	sl	3*4
15	Interferometer baseline	10^{-6} m	sl	3*4
16	Measurement Confident		ul	4
Measurements Group Repeated 20 times				
17	Window delay	10-12 s	sll	8
18	Spare		sl	4
19	OCOG width	Range bins*100	sl	4
20	OCOG or threshold	10^{-3} m	sl	4
21	Surface elevation derived	10^{-3} m	sl	4
22	AGC Channel 1	dB/100	sl	4
23	AGC Channel 2	dB/100	sl	4
24	Total fixed gain Ch1	dB/100	sl	4
25	Total fixed gain Ch2	dB/100	sl	4
26	Transmit Power	10^{-6} Watts	sl	4
27	Doppler range correction	10^{-3} m	sl	4
28	Instrument range	10^{-3} m	sl	4
29	Instrument range	10^{-3} m	sl	4
30	Spare		sl	4
31	Spare		sl	4
32	Internal phase correction	10^{-6} rad	sl	4
33	External phase correction	10^{-6} rad	sl	4
34	Noise power	dB/100	sl	4
35	Roll	10^{-3} Deg	ss	2
36	Pitch	10^{-3} Deg	ss	2
37	Yaw	10^{-3} Deg	ss	2
38	Spare		ss	2
39	Heading	10^{-3} Deg	sl	4
40	Standard deviation of roll	10^{-4} Deg	us	2
41	Standard deviation of	10^{-4} Deg	us	2
42	Standard deviation of yaw	10^{-4} Deg	us	2
Corrections Group Once per record				
	Empty for ASIRAS			
43	Spare		uc	64*1
Average pulse-width limited Waveform group Once per record				
	Empty for ASIRAS			
44	Spare		uc	8236*1

Identifier	Description	Units	Type	Size [Bytes]
Multilooked Waveform Group Repeated 20 times				
45	Multi-looked Power Echo.	Counts (0-65535)	us	4096*2
46	Linear scale factor, A		sl	4
47	Power of 2 scale factor,B		sl	4
48	Number of multilooked		us	2
49	Flags		us	2
50	Beam behaviour		us	50*2
Total				**177940**

4.2 GPS

Processed DGPS data is delivered in binary, big endian format with each record formated as described by Cullen (2010) and Table 20.

Table 20: GPS file format

Identifier	Description	Unit	Type	Size [Bytes]
1	Days (MJD)	UTC	sl	4
2	Seconds		ul	4
3	Microseconds		ul	4
4	Latitude	10^{-7} deg	sl	4
5	Longitude	10^{-7} deg	sl	4
6	Geodetic ellipsoidal height (WGS-84)	m	d	8
7	Spare_7	N/A	d	8
8	Spare_8	N/A	d	8
9	Spare_9	N/A	d	8
10	Spare_10	N/A	d	8
Total				**72**

4.3 INS

Processed INS data is delivered in binary, big endian format with each record formatted as described by Cullen (2010) and Table 21.

Table 21: INS file format

Identifier	Description	Unit	Type	Size [Bytes]
1	Days (MJD)	UTC	sl	4
2	Seconds		sl	4
3	Microseconds		sl	4
4	Latitude (WGS-84)	Deg	d	8
5	Longitude	Deg	d	8
6	Ground speed	Kts	d	8
7	True Track	Deg	d	8
8	True Heading	Deg	d	8
9	Wind Speed	Kts	d	8
10	Wind Direction	Deg	d	8
11	Magnetic Heading	Deg	d	8
12	Pitch	Deg	d	8
13	Roll	Deg	d	8
14	Pitch Rate	deg/s	d	8
15	Roll Rate	deg/s	d	8
16	Yaw Rate	deg/s	d	8
17	Body longitudinal	G	d	8
18	Body lateral Acceleration	G	d	8
19	Body normal acceleration	G	d	8
20	Vertical Acceleration in G	G	d	8
21	Velocity Inertial Vertical	ft/min	d	8
22	Velocity North-South	Kts	d	8
23	Velocity East-west	Kts	d	8
Total				**172**

4.4 Laser scanner (ALS)

Processed ALS data is delivered in binary, little endian format with each record formatted as described in Table 22. Note that time is in decimal hours since the beginning of the day with respect to UTC time.

Table 22: INS file format

Identifier	Description	Unit	Type	Size [Bytes]
Header				
1	Header Size	bytes	uc	1
2	Number of scan lines, N_{als_scan}	lines	ul	4
3	Number of data points per line, N_{als_dppl}	points	uc	1
4	Bytes per line, N_{als_bbl}	bytes	us	2
5	Bytes sec line	bytes	ull	8
6	Year of acquisition	UTC	us	2
7	Month of acquisition	UTC	uc	1
8	Day of acquisition	UTC	uc	1
9	Acquisition Start time (Seconds of day)	UTC	ul	4
10	Acquisition Stop time (Seconds of day)	UTC	ul	4
11	Device name		uc	8
Total				**36**
Time stamp array				
1	Array of time stamps for each scan line	UTC	ul	$4*N_{als\_scan}$
Total				$\mathbf{4*N_{als\_scan}}$
DEM Record Repeated N_{als_scan} times				
1	Array of time stamps for each point	UTC	d	$8*N_{als\_dppl}$
2	Array of latitudes for each point	degrees	d	$8*N_{als\_dppl}$
3	Array of longitudes for each point	degrees	d	$8*N_{als\_dppl}$
2	Array of ellipsoidal heights for each point	meter	d	$8*N_{als\_dppl}$
Total				$\mathbf{N_{als\_bbl}}$

4.5 Electromagnetic sounding (AEM)

The format of the EM datafiles (blank separated ASCII data) is given in table 23. All time tags are standard UTC time.

Table 23: EM data file format

Column	Description	Unit
1	Year	-
2	Month	-
3	Day	-
4	Second of the Day	-
5	Fiducial Number	-
6	Latitude	Deg
7	Longitude	Deg
8	Distance	m
9	Total Thickness	m
10	Laser Range	m

4.6 Vertical Camera

Approximate time and position of the vertical camera when a picture is taken is delivered in windows ASCII format as described in Table 24 and all individual pictures are in JPEG format. Each ASCII line gives the filename, time and position for the named picture. If no DGPS data is available the time and position is replaced with the string “No position available”.

Table 24: Position file format for vertical images

Identifier	Description	Unit
1	JPEG filename	
2	Decimal hours	hour
3	Latitude (WGS-84)	deg
4	Longitude	deg
5	Geodetic ellipsoidal height	m
6	Newline characters "\r \n"	

5 APPENDIX Processed GPS data in ESA format

Date	Filename	Start time (Sec of day)	Stop time (Sec of day)	File size
14-04-2011	GPS_R_01_20110414T162012_210551_0001	58812	75951	1.0
15-04-2011	GPS_F_01_20110415T144215_184247_0001	52935	67367	0.9
15-04-2011	GPS_R_01_20110415T193630_215314_0001	70590	78794	0.5
16-04-2011	GPS_R_01_20110416T134640_183801_0001	49600	67081	1.0
17-04-2011	GPS_R_01_20110417T131238_174457_0001	47558	63897	1.0
17-04-2011	GPS_R_01_20110417T190259_195708_0001	68579	71828	0.2
19-04-2011	GPS_R_01_20110419T120015_152055_0001	43215	55255	0.7
19-04-2011	GPS_R_01_20110419T152059_213204_0001	55259	77524	2.7
26-04-2011	GPS_R_01_20110426T115801_170032_0001	43081	61232	1.1
27-04-2011	GPS_R_01_20110427T102817_173231_0001	37697	63151	3.0
28-04-2011	GPS_R_01_20110428T090034_123633_0001	32434	45393	1.6
28-04-2011	GPS_R_01_20110428T134816_163749_0001	49696	59869	1.2
30-04-2011	GPS_R_01_20110430T055318_110716_0001	21198	40036	1.1
30-04-2011	GPS_R_01_20110430T110958_155251_0001	40198	57171	1.0
02-05-2011	GPS_R_01_20110502T133726_191635_0001	49046	69395	1.2
03-05-2011	GPS_R_01_20110503T110746_171915_0001	40066	62355	1.3
03-05-2011	GPS_F_01_20110503T171913_204445_0001	62353	74685	0.7
06-05-2011	GPS_R_01_20110506T101600_154634_0001	36960	56794	2.4
07-05-2011	GPS_R_01_20110507T153352_210516_0001	56032	75916	1.2
08-05-2011	GPS_R_01_20110508T131947_192531_0001	47987	69931	2.6
09-05-2011	GPS_R_01_20110509T115048_144849_0001	42648	53329	0.6

6 APPENDIX Processed INS data in ESA format

Date	Filename	Start time (Sec of day)	Stop time (Sec of day)	File size (Mb)
14-04-2011	INS_20110414T165544_210547_0001	60944	75947	25.8
15-04-2011	INS_20110415T150212_184120_0001	54132	67280	22.6
15-04-2011	INS_20110415T194524_215258_0001	71124	78778	13.2
16-04-2011	INS_20110416T141150_183711_0001	51110	67031	27.4
17-04-2011	INS_20110417T135339_174405_0001	50019	63845	23.8
17-04-2011	INS_20110417T191622_195655_0001	69382	71815	4.2
19-04-2011	INS_20110419T125611_153623_0001	46571	56183	16.5
19-04-2011	INS_20110419T153700_213032_0001	56220	77432	36.5
26-04-2011	INS_20110426T123240_170000_0001	45160	61200	27.6
27-04-2011	INS_20110427T110546_173145_0001	39946	63105	38.7
28-04-2011	INS_20110428T092029_123614_0001	33629	45374	20.2
28-04-2011	INS_20110428T135000_163701_0001	49800	59821	17.2
30-04-2011	INS_20110430T061456_110450_0001	22496	39890	29.9
30-04-2011	INS_20110430T114900_155240_0001	42540	57160	25.1
02-05-2011	INS_20110502T135638_191548_0001	50198	69348	32.9
03-05-2011	INS_20110503T114209_171748_0001	42129	62268	34.6
03-05-2011	INS_20110503T171829_204451_0001	62309	74691	21.3
06-05-2011	INS_20110506T105900_154536_0001	39540	56736	29.6
07-05-2011	INS_20110507T155512_210504_0001	57312	75904	32.0
08-05-2011	INS_20110508T134515_192422_0001	49515	69862	35.0
09-05-2011	INS_20110509T120820_144802_0001	43700	53282	16.5

7 APPENDIX Processed ALS data in ESA format

Date	Filename	Start time (Sec of day)	Stop time (Sec of day)	File size (Mb)
16-04-2011	ALS_L1B_D2_20110416T141648_145757	51408	53877	117.5
16-04-2011	ALS_L1B_D2_20110416T150000_160031	54000	57631	173.3
16-04-2011	ALS_L1B_D2_20110416T160200_170038	57720	61238	167.5
16-04-2011	ALS_L1B_D2_20110416T170200_173329	61320	63209	89.3
26-04-2011	ALS_L1B_D2_20110426T131300_140748	47580	50868	213.2
26-04-2011	ALS_L1B_D2_20110426T140900_150340	50940	54220	212.7
26-04-2011	ALS_L1B_D2_20110426T150430_154048	54270	56448	141.3
26-04-2011	ALS_L1B_D2_20110426T154130_164638	56490	60398	253.4
27-04-2011	ALS_L1B_D2_20110427T111130_115825	40290	43105	182.4
27-04-2011	ALS_L1B_D2_20110427T120000_125834	43200	46714	227.9
27-04-2011	ALS_L1B_D2_20110427T130000_140516	46800	50716	252.6
27-04-2011	ALS_L1B_D2_20110427T154530_165800	56730	61080	281.9
30-04-2011	ALS_L1B_D2_20110430T070800_075207	25680	28327	171.7
30-04-2011	ALS_L1B_D2_20110430T075304_084818	28384	31698	214.3
30-04-2011	ALS_L1B_D2_20110430T084900_093208	31740	34328	167.9
30-04-2011	ALS_L1B_D2_20110430T093300_095815	34380	35895	98.0
30-04-2011	ALS_L1B_D2_20110430T125454_132247	46494	48167	108.5
30-04-2011	ALS_L1B_D2_20110430T140159_143139	50519	52299	115.5
02-05-2011	ALS_L1B_D2_20110502T140100_145859	50460	53939	225.3
02-05-2011	ALS_L1B_D2_20110502T150000_155556	54000	57356	217.7
02-05-2011	ALS_L1B_D2_20110502T155630_165412	57390	60852	224.5
02-05-2011	ALS_L1B_D2_20110502T165500_175807	60900	64687	245.5
02-05-2011	ALS_L1B_D2_20110502T175830_185604	64710	68164	219.5
06-05-2011	ALS_L1B_D2_20110506T105530_115937	39330	43177	249.5
06-05-2011	ALS_L1B_D2_20110506T120030_130006	43230	46806	231.9
06-05-2011	ALS_L1B_D2_20110506T130100_140102	46860	50462	233.6
06-05-2011	ALS_L1B_D2_20110506T140130_150055	50490	54055	231.2
06-05-2011	ALS_L1B_D2_20110506T150130_151501	54090	54901	51.6
07-05-2011	ALS_L1B_D2_20110507T173001_180242	63001	64962	119.5
07-05-2011	ALS_L1B_D2_20110507T180330_183704	65010	67024	129.1
07-05-2011	ALS_L1B_D2_20110507T183800_190055	67080	68455	88.5
07-05-2011	ALS_L1B_D2_20110507T190730_192453	68850	69893	66.8
09-05-2011	ALS_L1B_D2_20110509T123800_132957	45480	48597	202.2

8 APPENDIX Processed ALS data ESA format full resolution

Date	Filename	Start time (Sec of day)	Stop time (Sec of day)	File size (Mb)
16-04-2011	ALS_L1B_20110416T141648_145757	51408	53877	588.8
17-04-2011	ALS_L1B_20110417T192400_192547	69840	69947	27.4
17-04-2011	ALS_L1B_20110417T194535_194604	71135	71164	7.5
17-04-2011	ALS_L1B_20110417T195009_195042	71409	71442	8.4
30-04-2011	ALS_L1B_20110430T070800_075207	25680	28327	858.4
30-04-2011	ALS_L1B_20110430T075300_084818	28380	31698	1074.3
30-04-2011	ALS_L1B_20110430T084900_093208	31740	34328	839.5
30-04-2011	ALS_L1B_20110430T093300_095815	34380	35895	490.6
30-04-2011	ALS_L1B_20110430T140159_143139	50519	52299	577.3
07-05-2011	ALS_L1B_20110507T173001_180242	63001	64962	599.6
07-05-2011	ALS_L1B_20110507T180330_183704	65010	67024	648.2
07-05-2011	ALS_L1B_20110507T183800_190055	67080	68455	445.8
07-05-2011	ALS_L1B_20110507T190730_192453	68850	69893	335.5
09-05-2011	ALS_L1B_20110509T131200_131441	47520	47681	52.5

9 APPENDIX Processed ASIRAS profiles

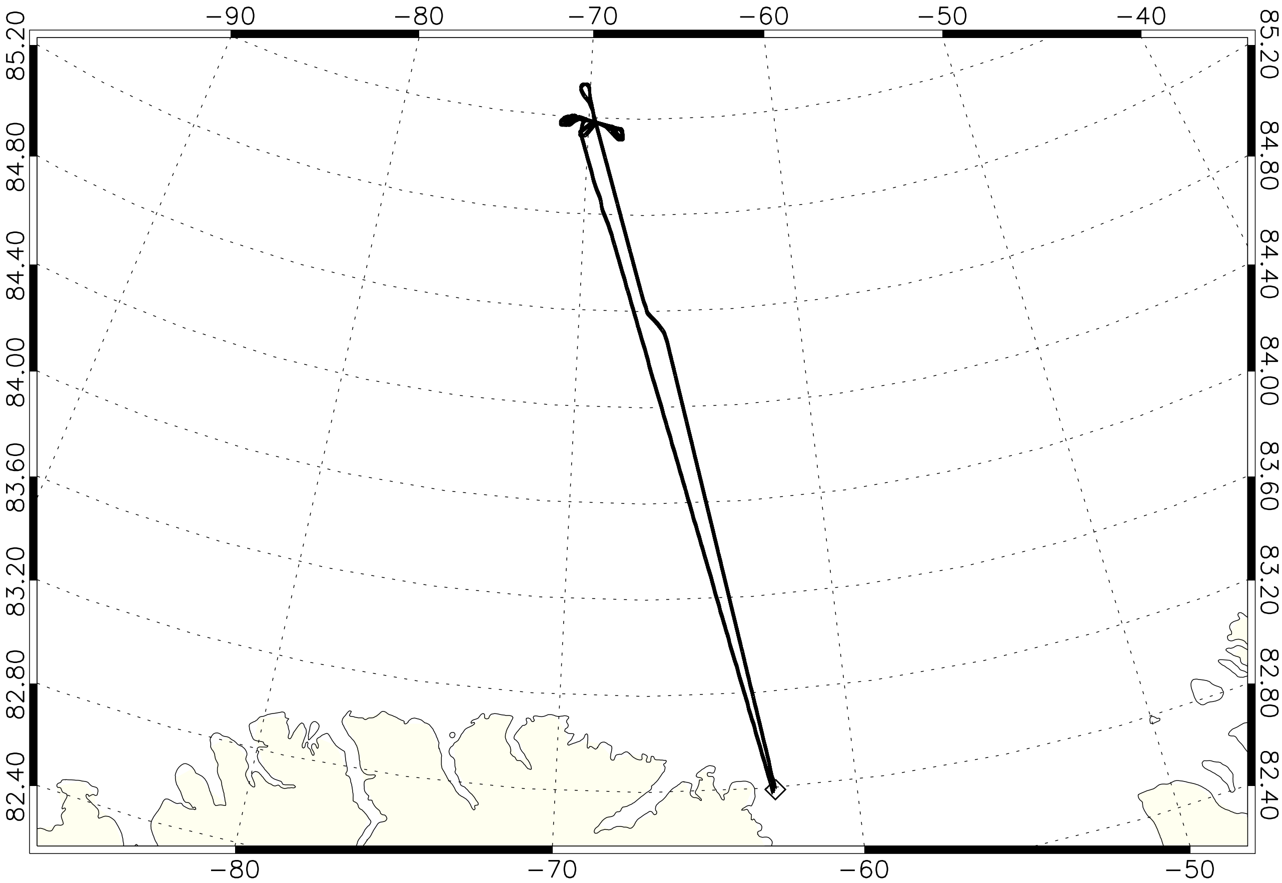
Following plots show all processed ASIRAS profiles. Each profile plot consists of four parts:

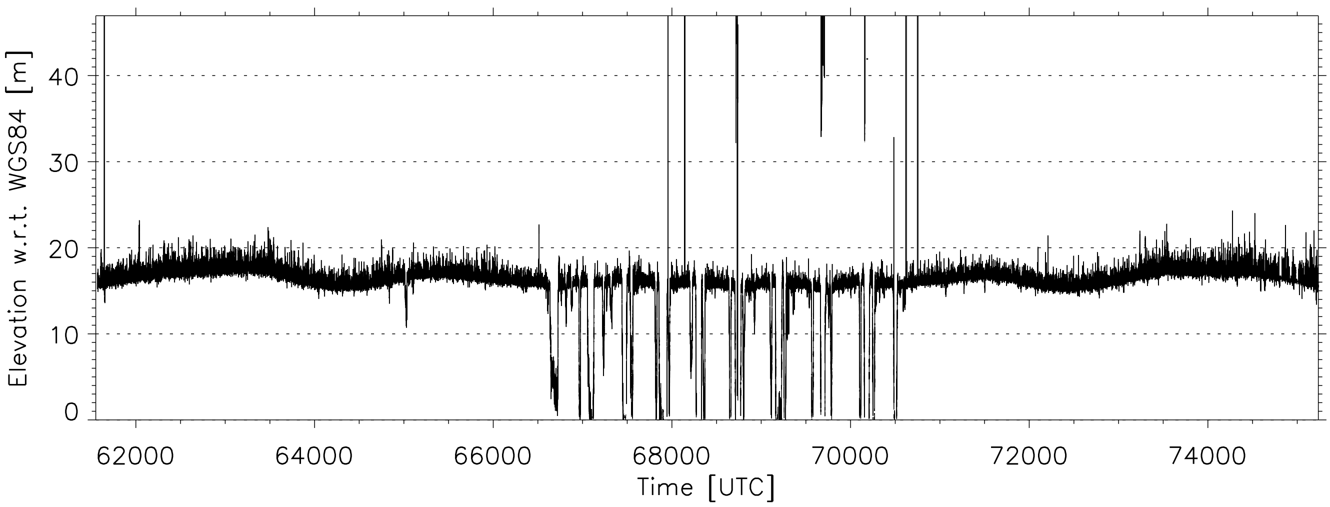
1. Header composed of daily profile number and the date and a sub-header with the filename.
2. Geographical plot of the profile (diamond indicates the start of the profile).
3. Rough indication of the heights as determined with the OCOG retracker plotted versus time of day in seconds.
4. Info box with date, start and stop times in hour, minute, seconds, and in square brackets seconds of the day, acquisition mode etc.

It should be emphasized that the surface height determined by the OCOG retracker is a rough estimate and not a true height.

A110414_00

AS30A00_ASIWL1B040320110414T170551_20110414T205357_0001.DBL

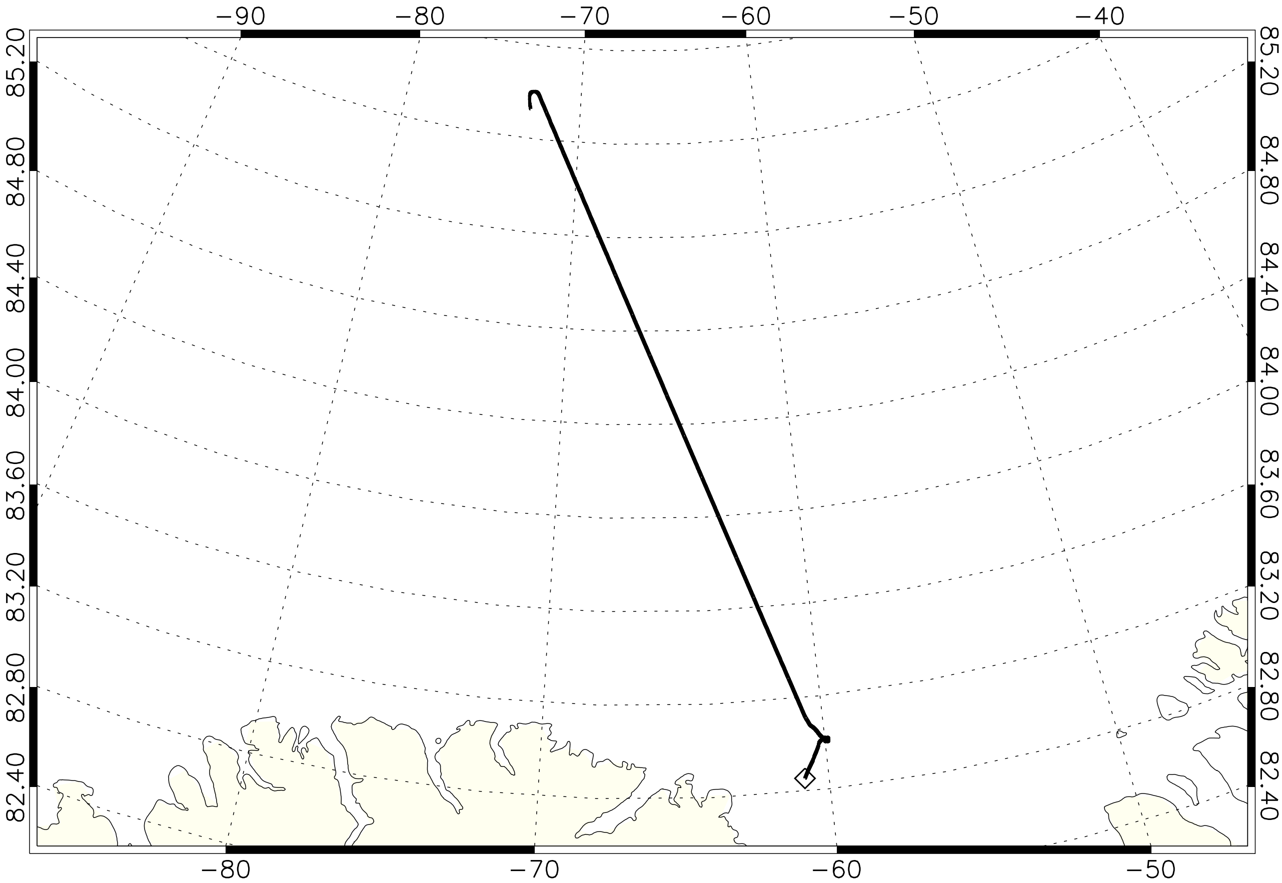


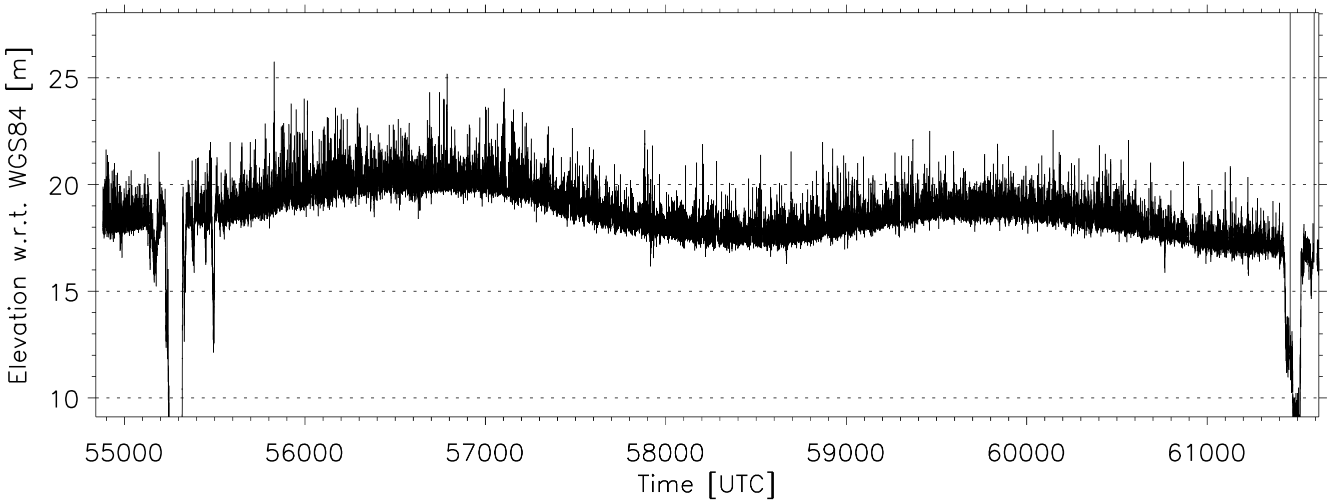


Date	2011-04-14	**Instrument Mode**	Adv. Low Altitude
Start Time	17:05:51 (61551)	**Aircraft**	DNSC Twin Otter
Stop Time	20:53:56 (75236)	**Retracker**	OCOG
Distance	929.799 km	**INS Resolution**	50 Hz
Duration	03 h 48 m 05 s	**Processor Version**	0403

A110415_00

AS3OA00_ASIWL1B040320110415T151401_20110415T170659_0001.DBL

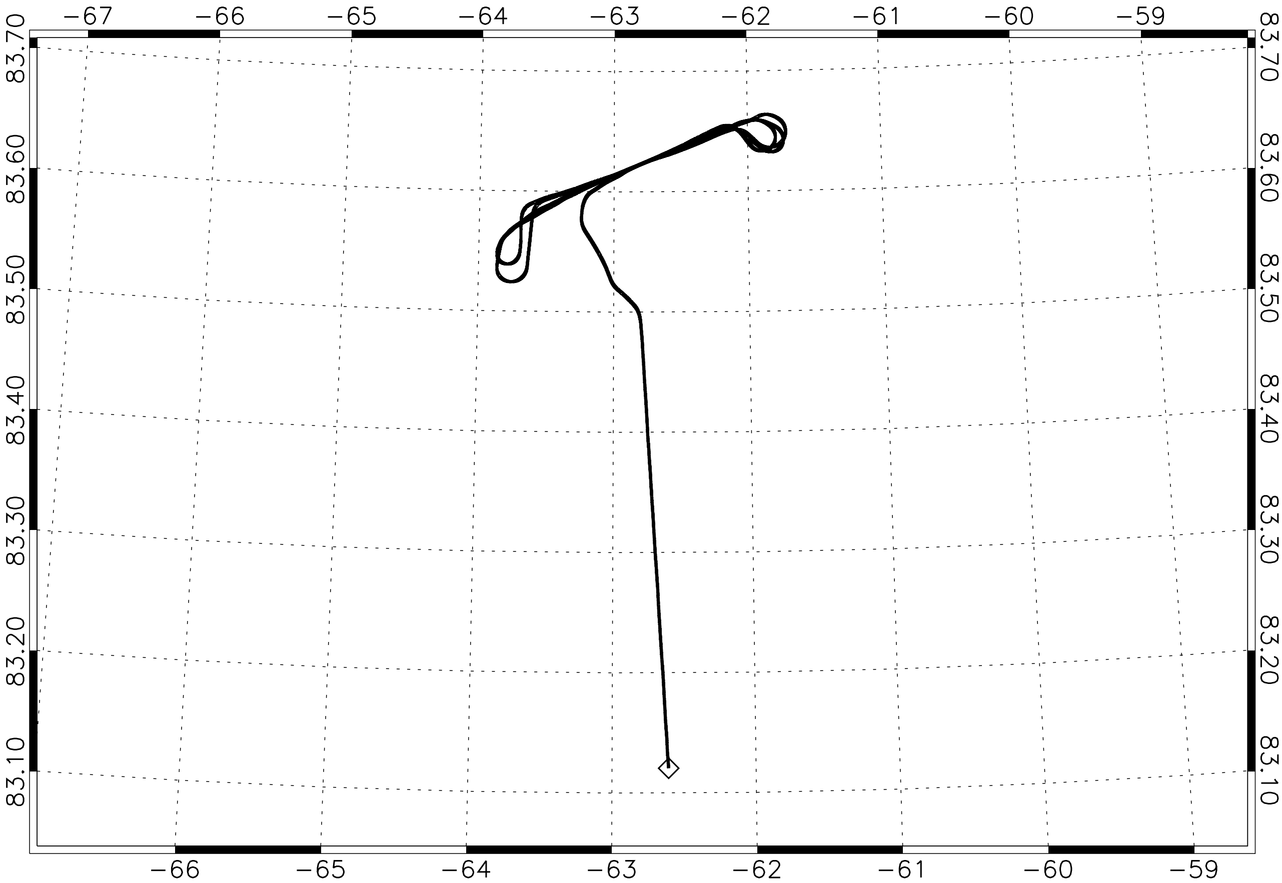


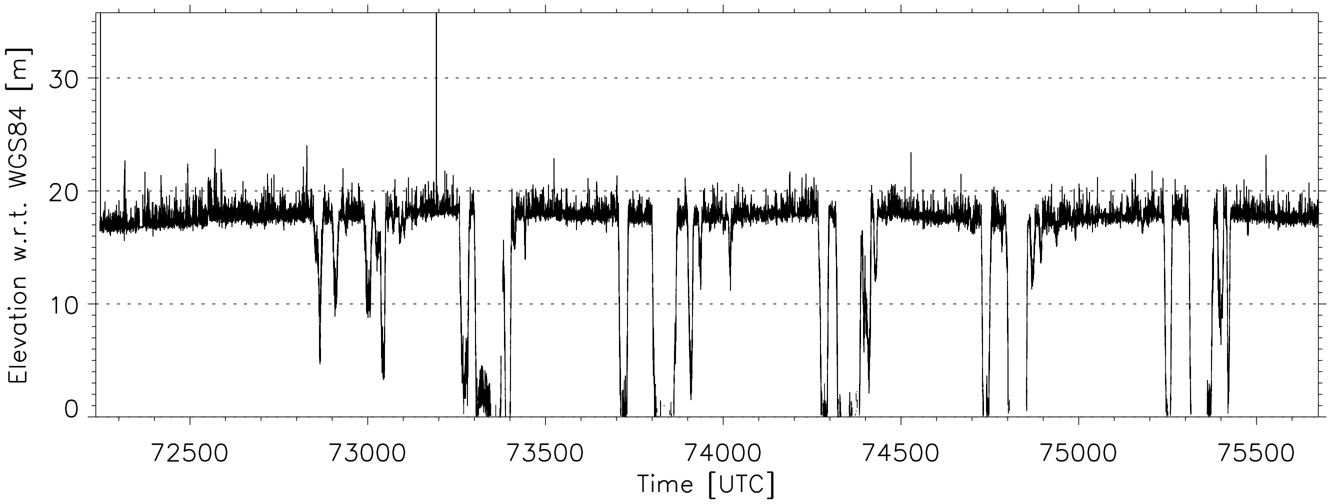


Date	2011-04-15	**Instrument Mode**	Adv. Low Altitude
Start Time	15:14:01 (54841)	**Aircraft**	DNSC Twin Otter
Stop Time	17:06:58 (61618)	**Retracker**	OCOG
Distance	376.629 km	**INS Resolution**	50 Hz
Duration	01 h 52 m 58 s	**Processor Version**	0403

A110415_01

AS3OA01_ASIWL1B040320110415T200355_20110415T210114_0001.DBL

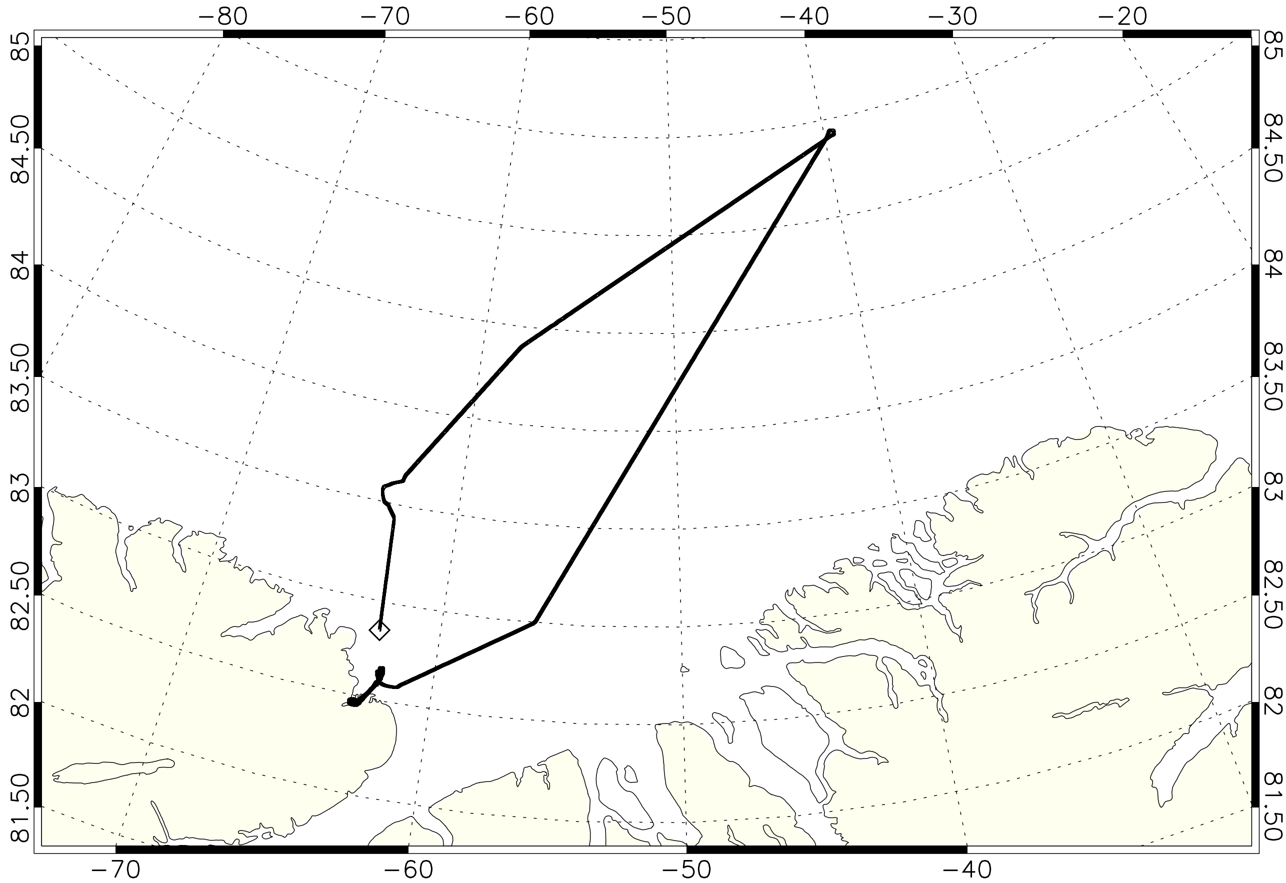


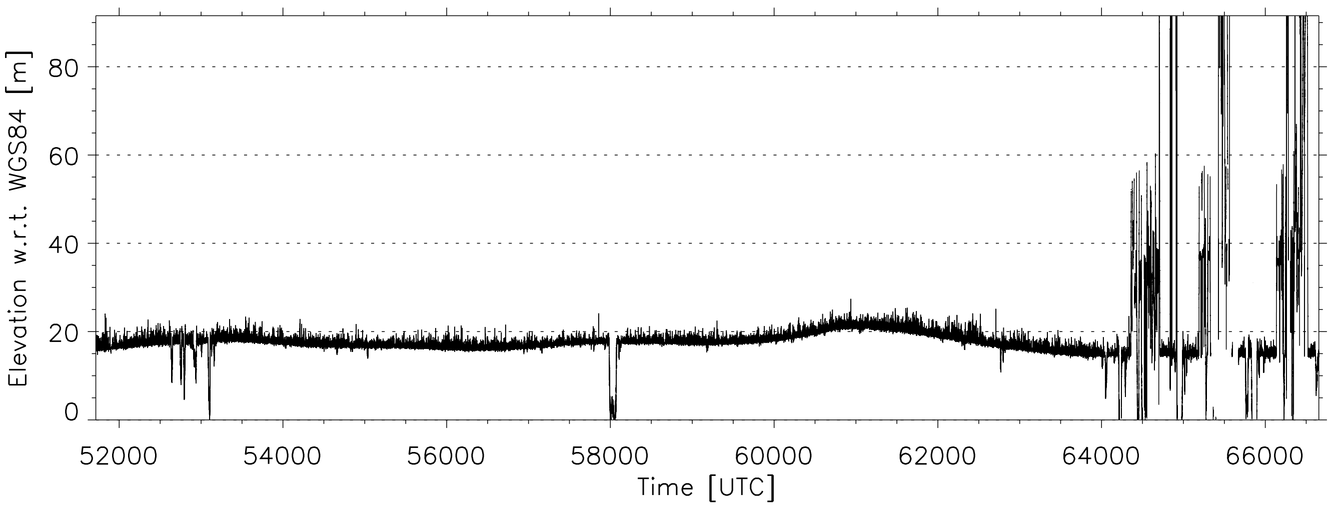


Date	2011-04-15	**Instrument Mode**	Adv. Low Altitude
Start Time	20:03:55 (72235)	**Aircraft**	DNSC Twin Otter
Stop Time	21:01:13 (75673)	**Retracker**	OCOG
Distance	229.364 km	**INS Resolution**	50 Hz
Duration	00 h 57 m 19 s	**Processor Version**	0403

A110416_00

AS3OA00_ASIWL1B040320110416T142154_20110416T183055_0001.DBL

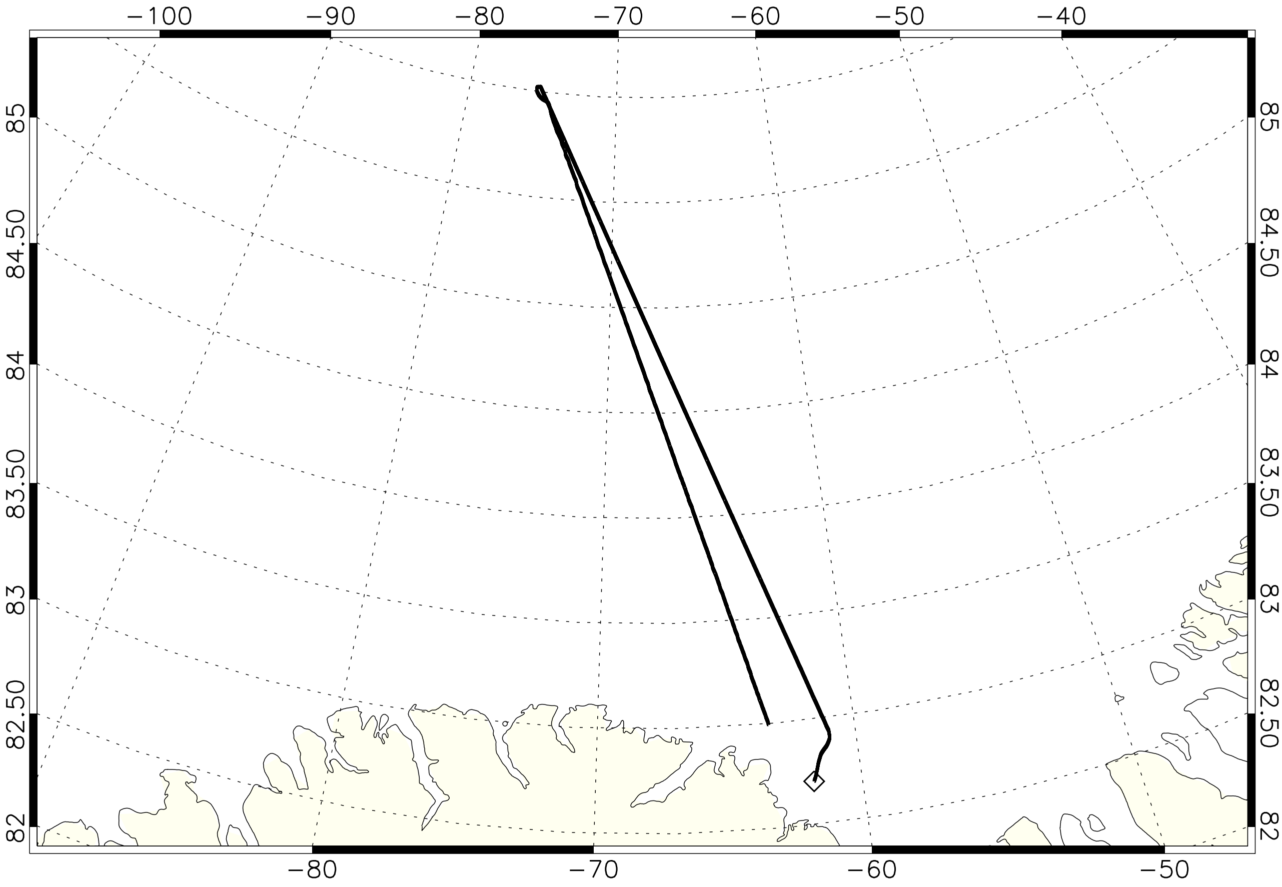


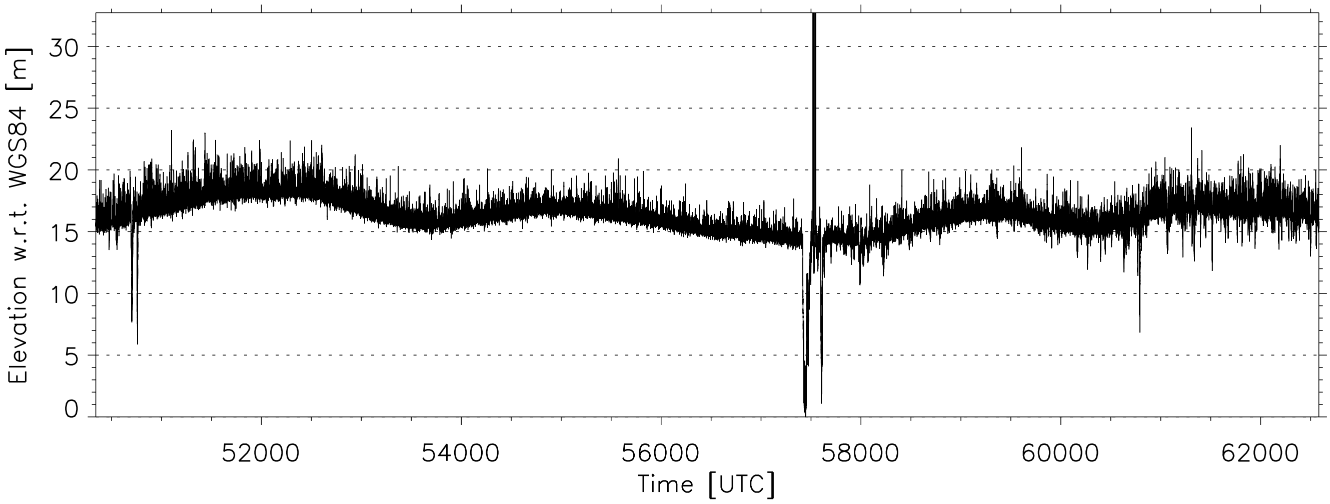


Date	2011-04-16	**Instrument Mode**	Adv. Low Altitude
Start Time	14:21:54 (51714)	**Aircraft**	DNSC Twin Otter
Stop Time	18:30:54 (66654)	**Retracker**	OCOG
Distance	1004.842 km	**INS Resolution**	50 Hz
Duration	04 h 09 m 00 s	**Processor Version**	0403

A110417_00

AS3OA00_ASIWL1B040320110417T135903_20110417T172302_0001.DBL

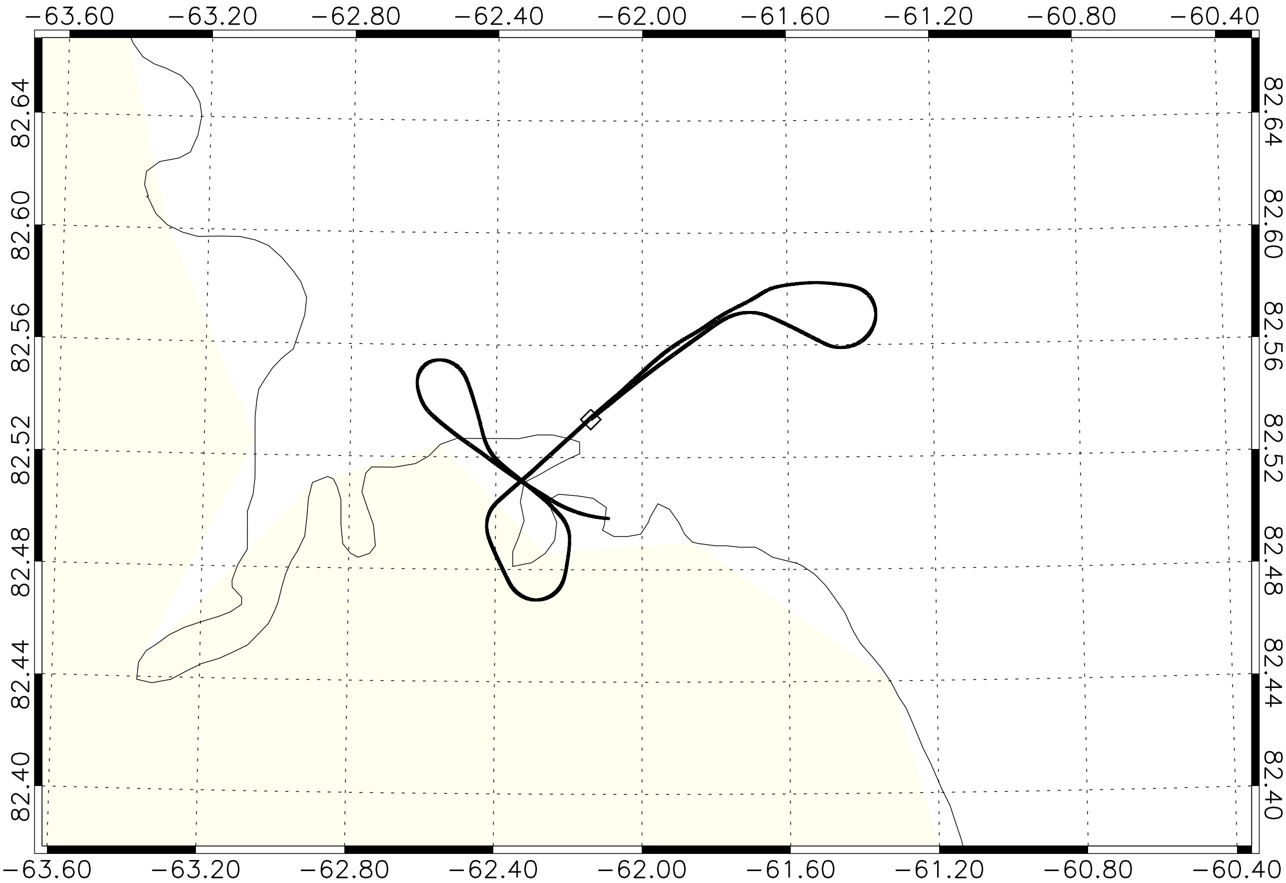


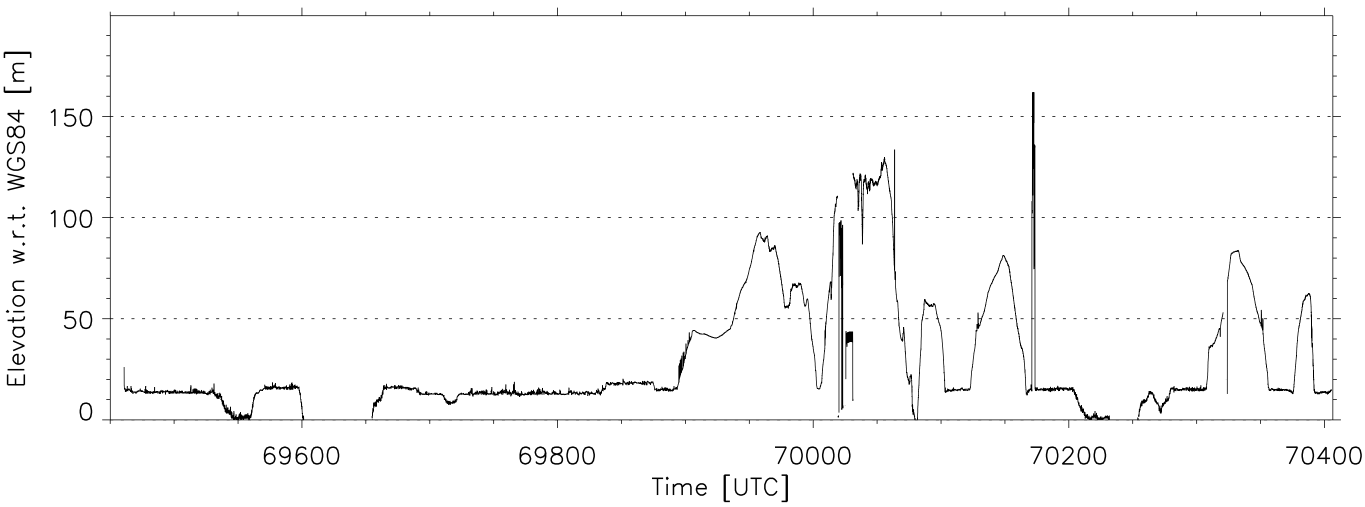


Date	2011−04−17	**Instrument Mode**	Adv. Low Altitude
Start Time	13:59:03 (50343)	**Aircraft**	DNSC Twin Otter
Stop Time	17:23:01 (62581)	**Retracker**	OCOG
Distance	763.999 km	**INS Resolution**	50 Hz
Duration	03 h 23 m 59 s	**Processor Version**	0403

A110417_01

AS30A01_ASIWL1B040320110417T191730_20110417T193452_0001.DBL

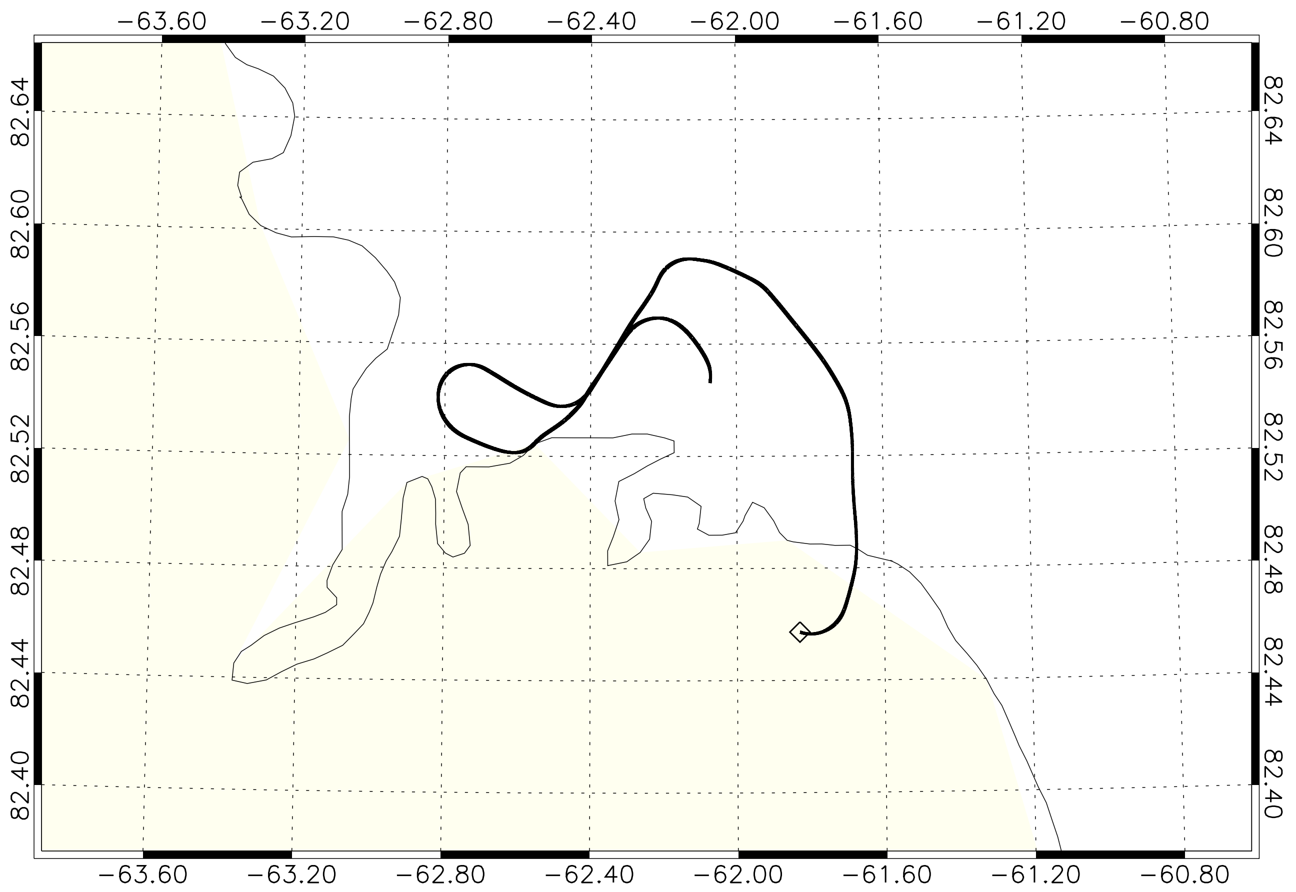


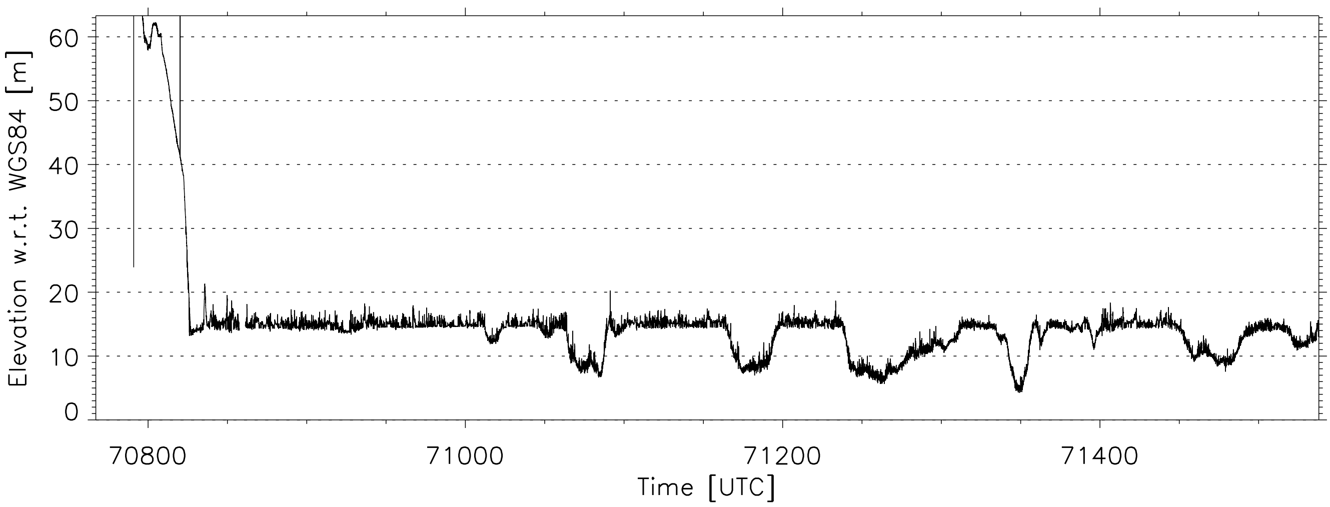


Date	2011−04−17	**Instrument Mode**	Adv. Low Altitude
Start Time	19:17:30 (69450)	**Aircraft**	DNSC Twin Otter
Stop Time	19:33:26 (70406)	**Retracker**	OCOG
Distance	60.622 km	**INS Resolution**	50 Hz
Duration	00 h 15 m 57 s	**Processor Version**	0403

A110417_02

AS3OA02_ASIWL1B040320110417T193927_20110417T195218_0001.DBL

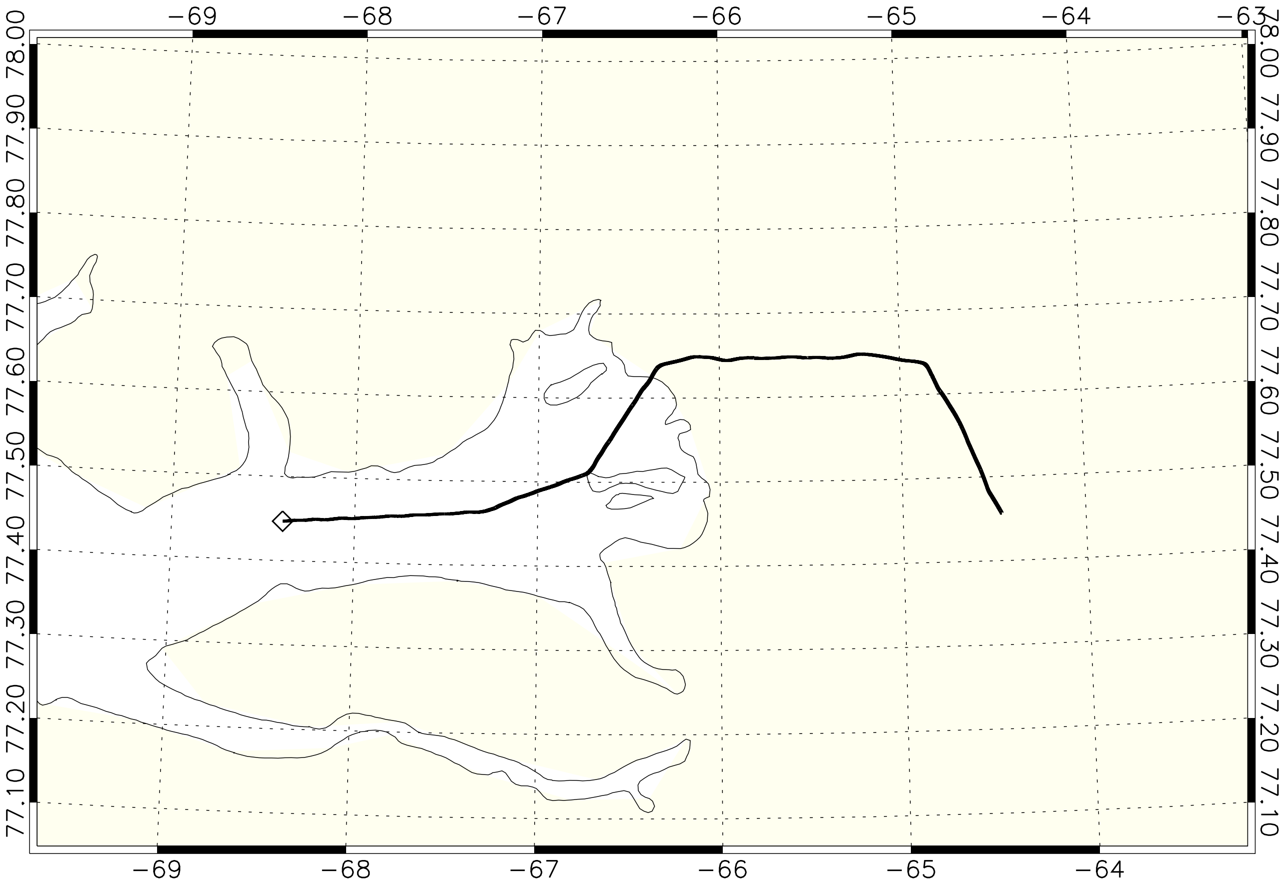


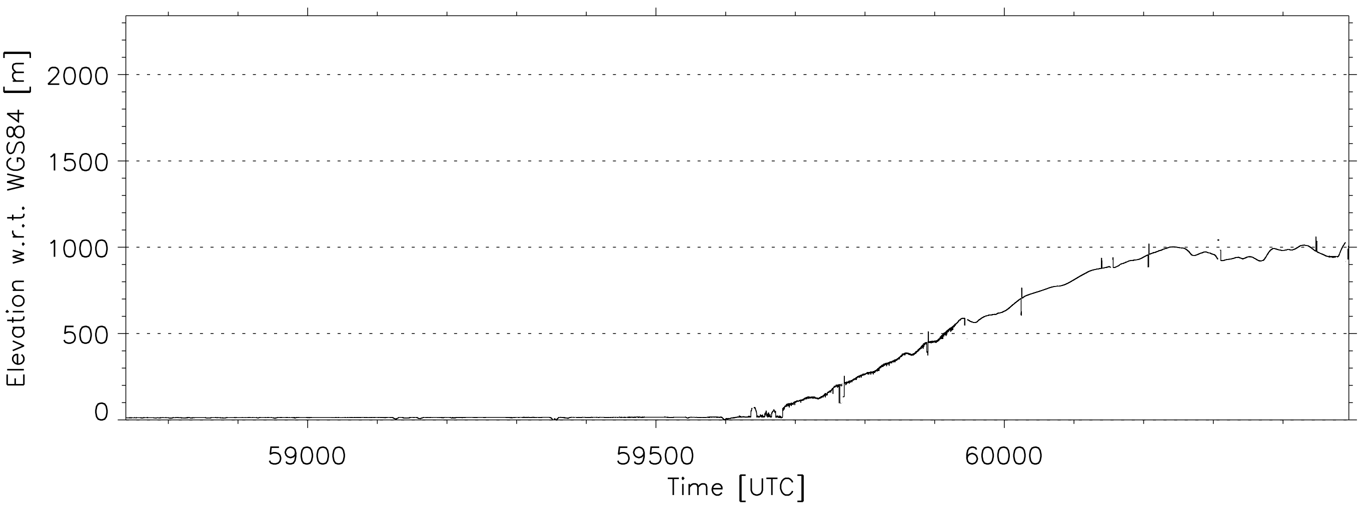


Date	2011-04-17	**Instrument Mode**	Adv. Low Altitude
Start Time	19:39:27 (70767)	**Aircraft**	DNSC Twin Otter
Stop Time	19:52:17 (71537)	**Retracker**	OCOG
Distance	49.248 km	**INS Resolution**	50 Hz
Duration	00 h 12 m 51 s	**Processor Version**	0403

A110419_04

AS30A04_ASIWL1B040320110419T161859_20110419T164857_0001.DBL

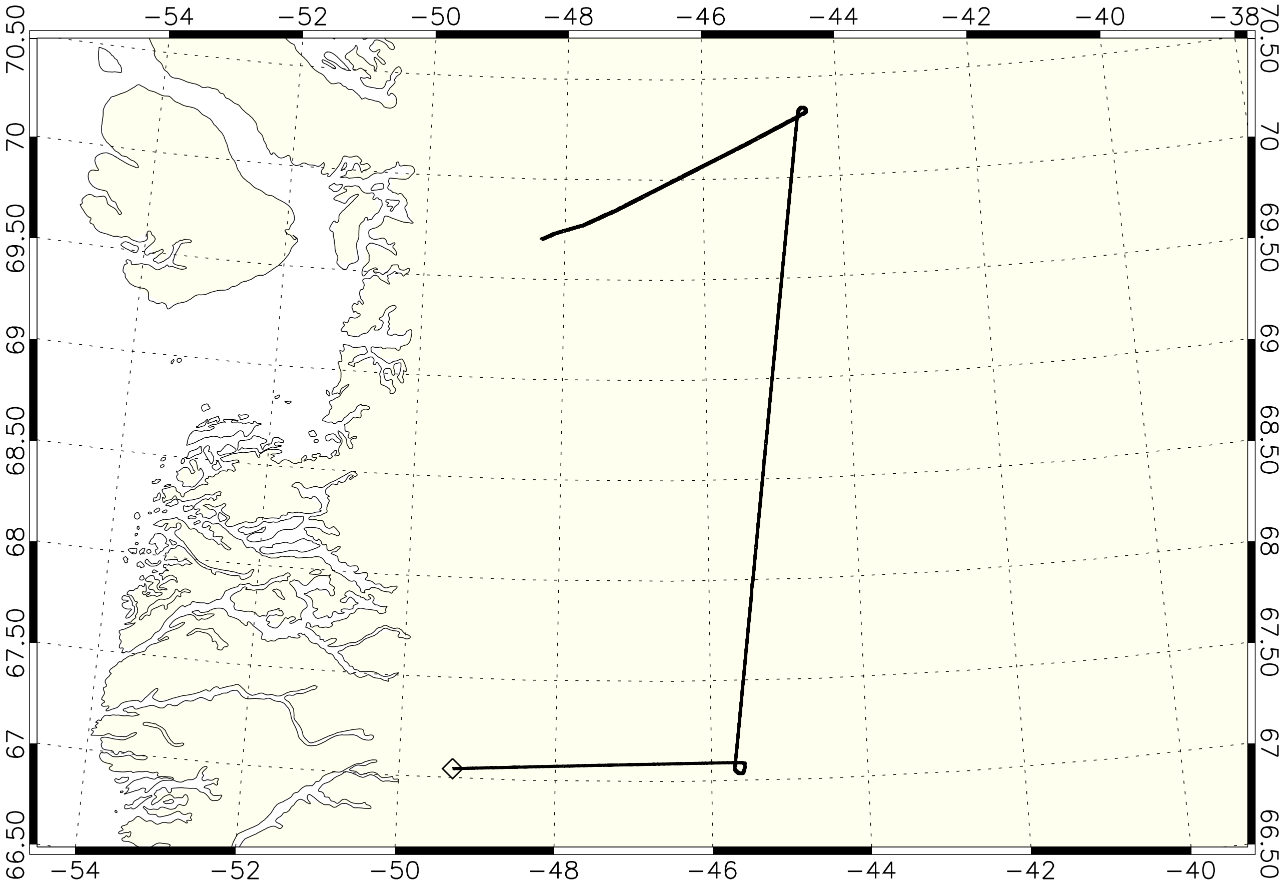


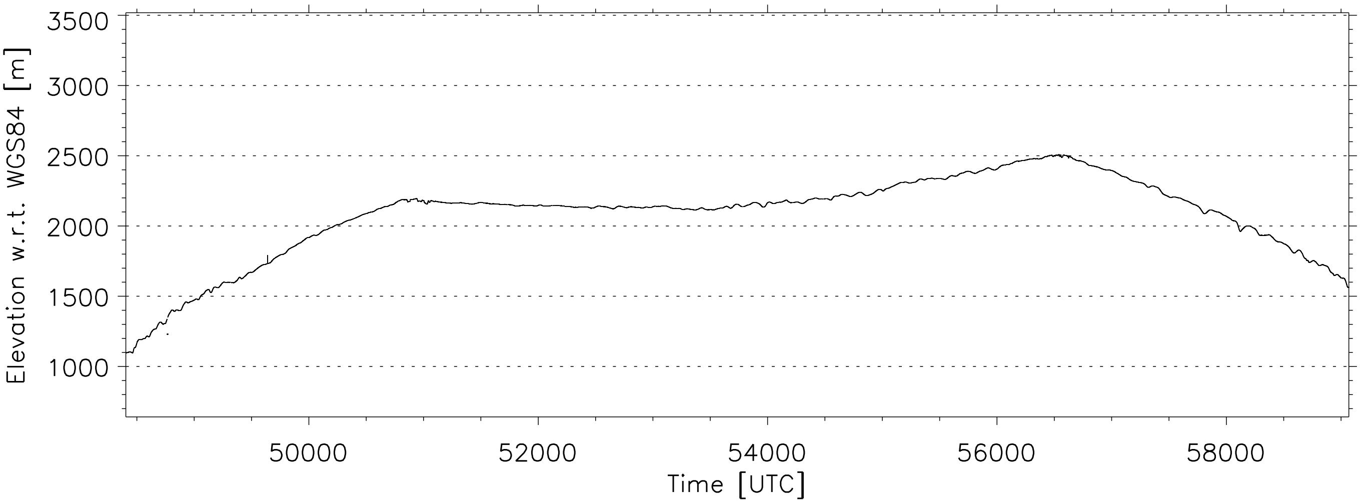


Date	2011-04-19	**Instrument Mode**	Adv. Low Altitude
Start Time	16:18:59 (58739)	**Aircraft**	DNSC Twin Otter
Stop Time	16:48:14 (60494)	**Retracker**	OCOG
Distance	116.007 km	**INS Resolution**	50 Hz
Duration	00 h 29 m 15 s	**Processor Version**	0403

A110426_00

AS3OA00_ASIWL1B040320110426T132644_20110426T162428_0001.DBL

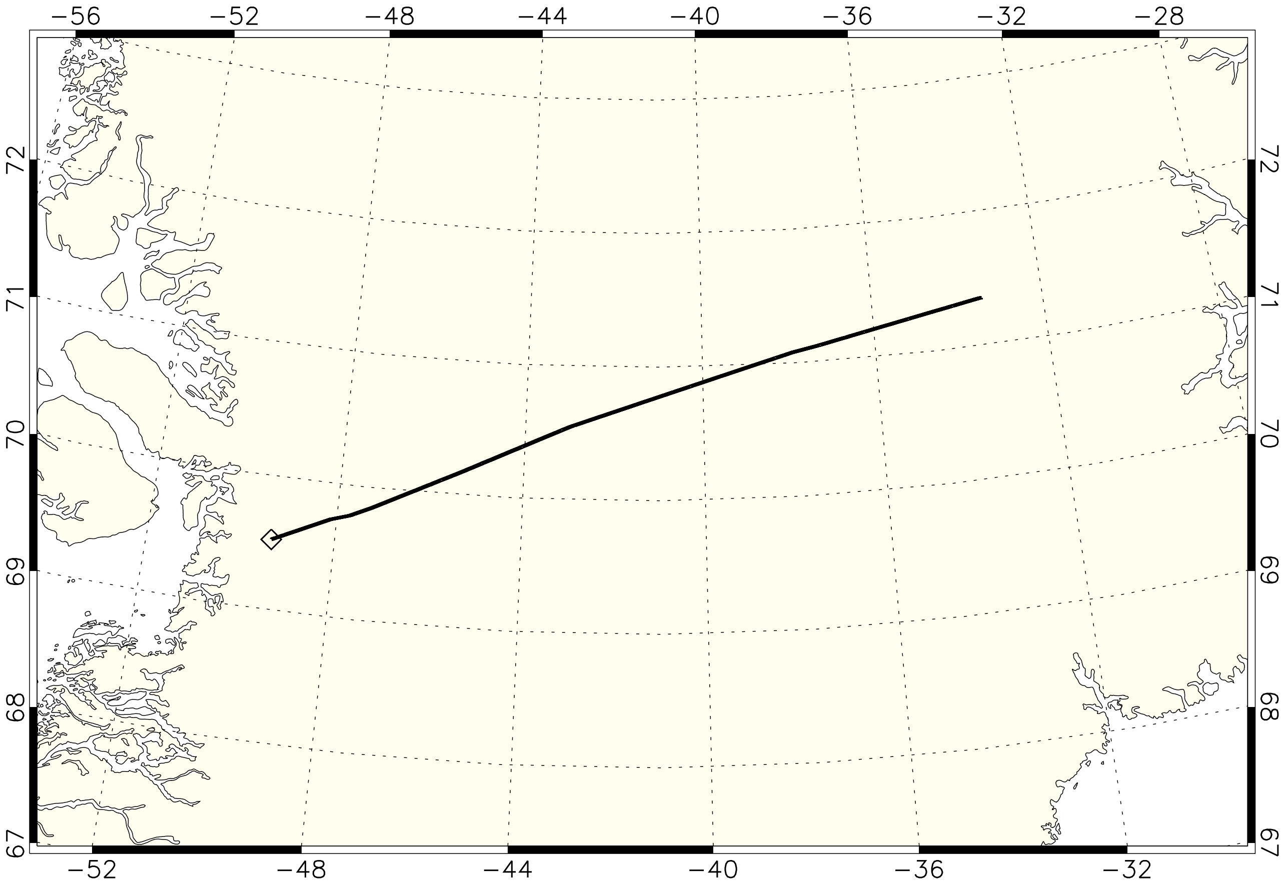


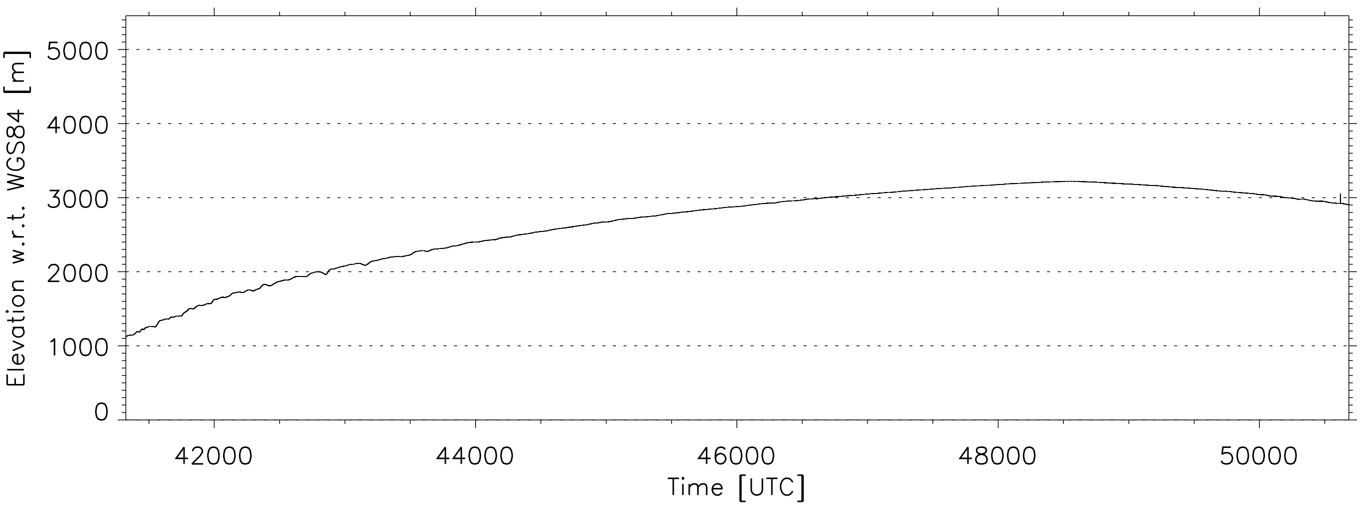


Date	2011-04-26	**Instrument Mode**	Adv. Low Altitude
Start Time	13:26:44 (48404)	**Aircraft**	DNSC Twin Otter
Stop Time	16:24:27 (59067)	**Retracker**	OCOG
Distance	710.931 km	**INS Resolution**	50 Hz
Duration	02 h 57 m 44 s	**Processor Version**	0403

A110427_00

AS3OA00_ASIWL1B040320110427T112843_20110427T140445_0001.DBL

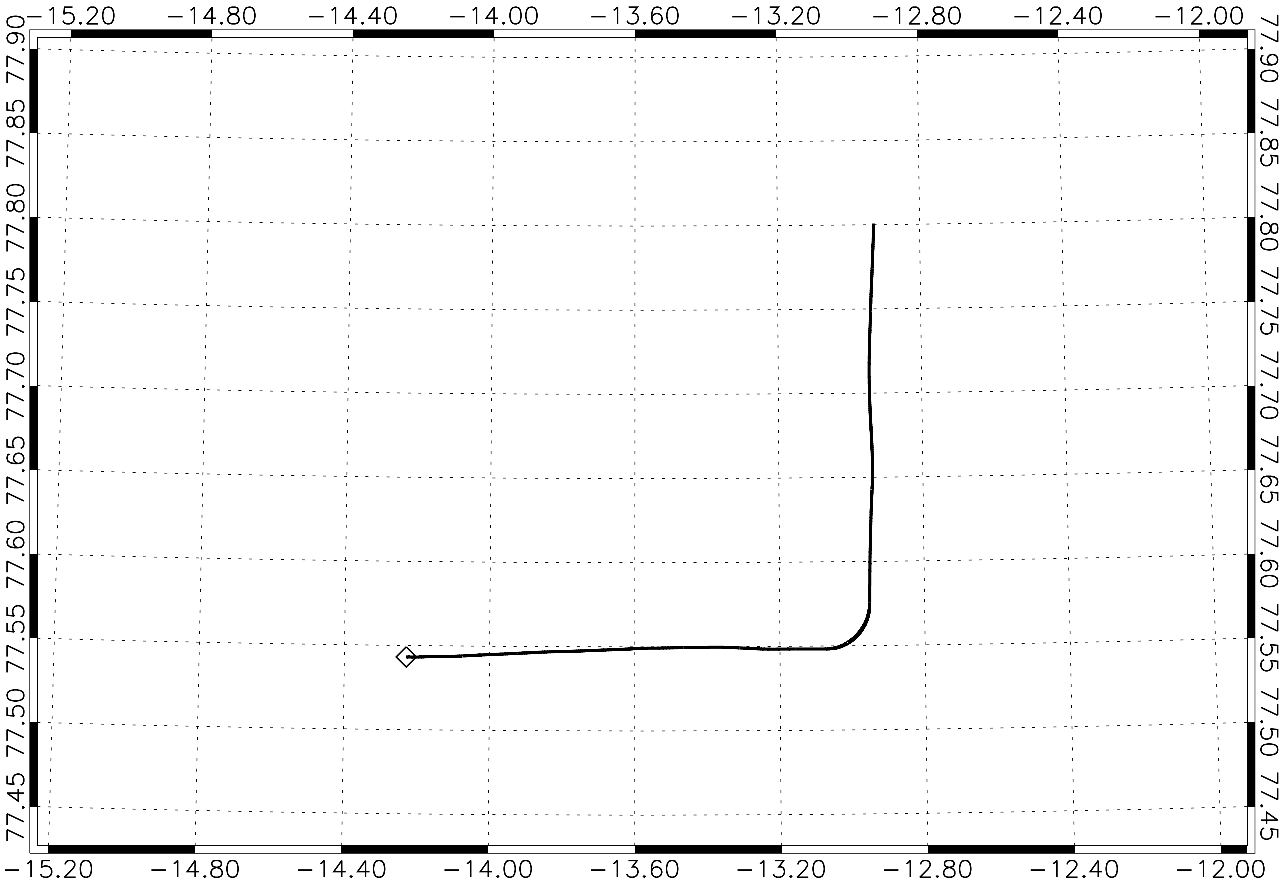


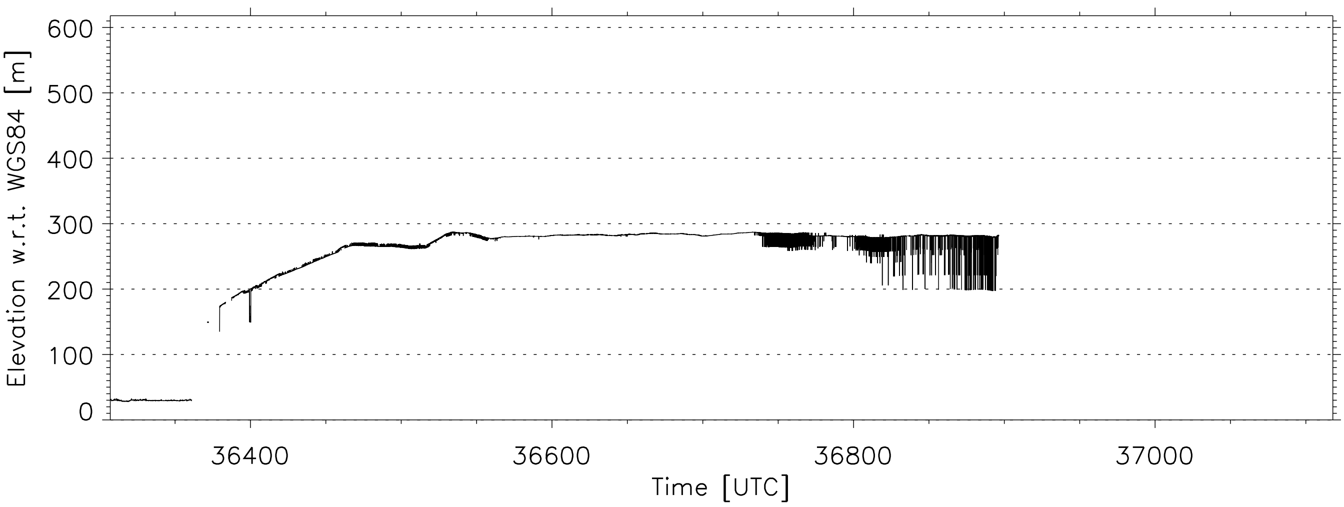


Date	2011−04−27	**Instrument Mode**	Adv. Low Altitude
Start Time	11:28:43 (41323)	**Aircraft**	DNSC Twin Otter
Stop Time	14:04:44 (50684)	**Retracker**	OCOG
Distance	624.041 km	**INS Resolution**	50 Hz
Duration	02 h 36 m 01 s	**Processor Version**	0403

A110428_00

AS3OA00_ASIWL1B040320110428T100507_20110428T101838_0001.DBL

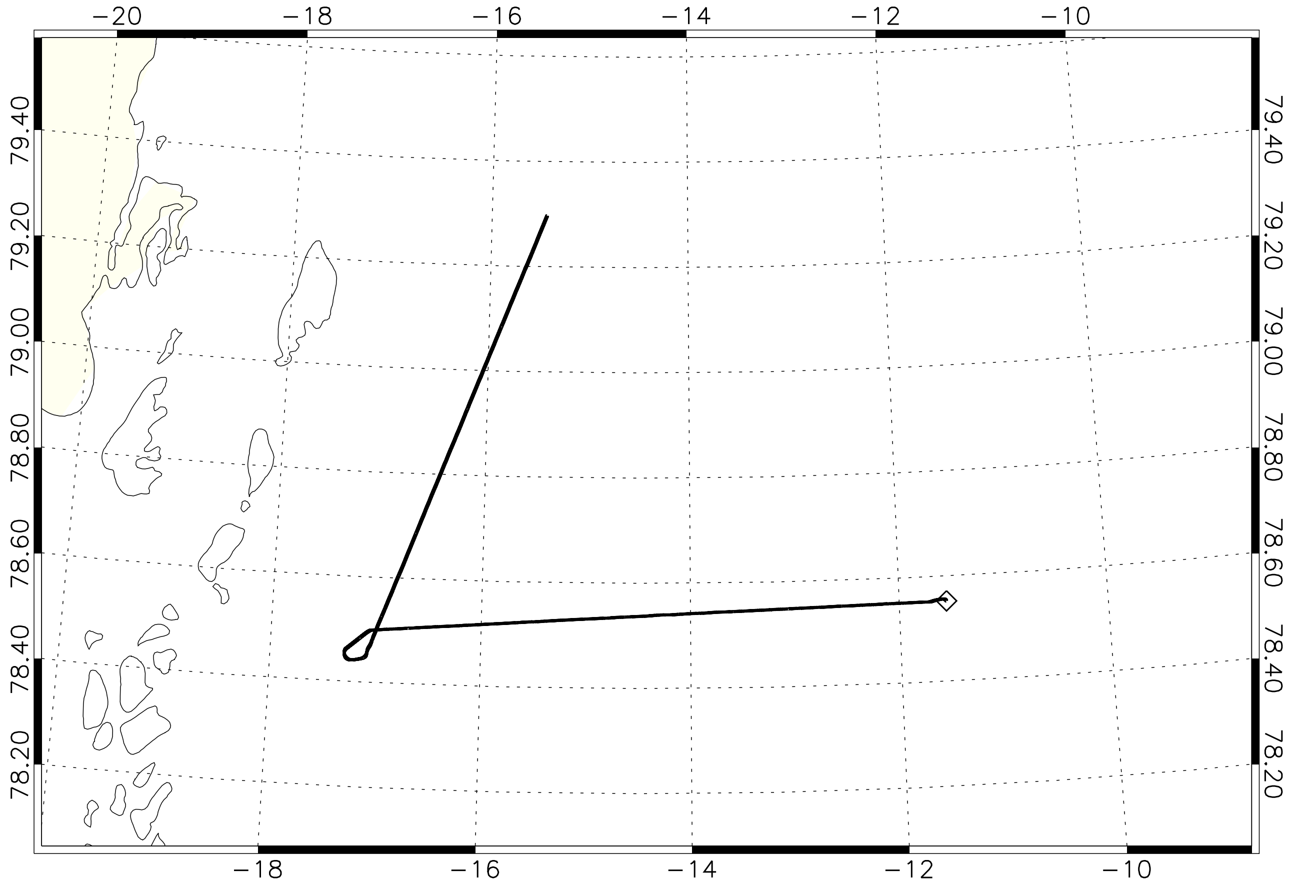


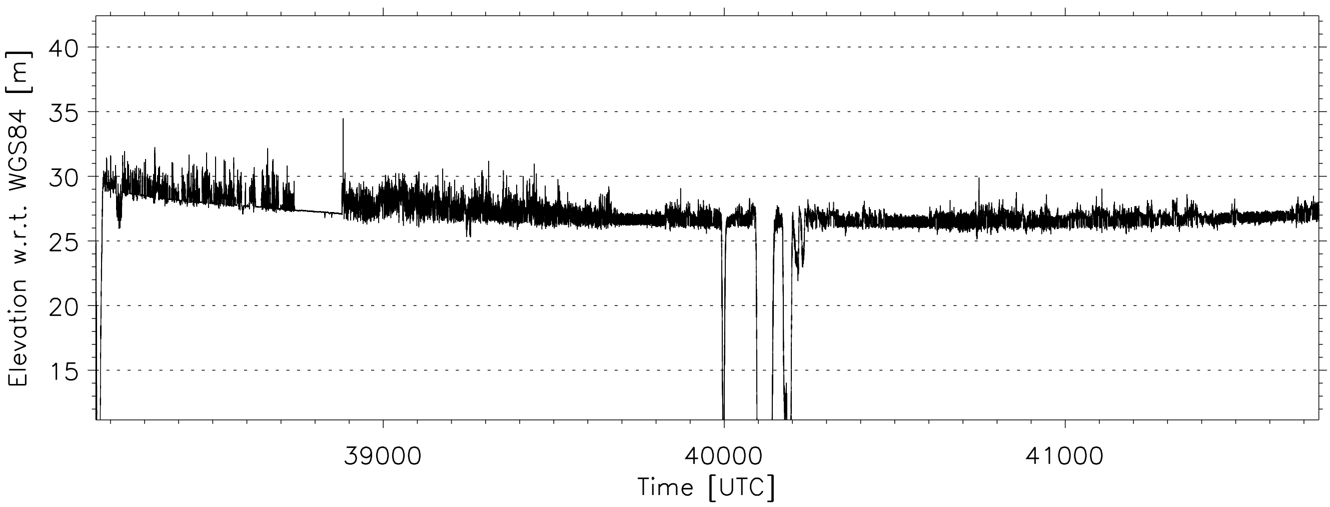


Date	2011−04−28	**Instrument Mode**	Adv. Low Altitude
Start Time	10:05:07 (36307)	**Aircraft**	DNSC Twin Otter
Stop Time	10:18:37 (37117)	**Retracker**	OCOG
Distance	57.428 km	**INS Resolution**	50 Hz
Duration	00 h 13 m 31 s	**Processor Version**	0403

A110428_01

AS30A01_ASIWL1B040320110428T103557_20110428T113544_0001.DBL

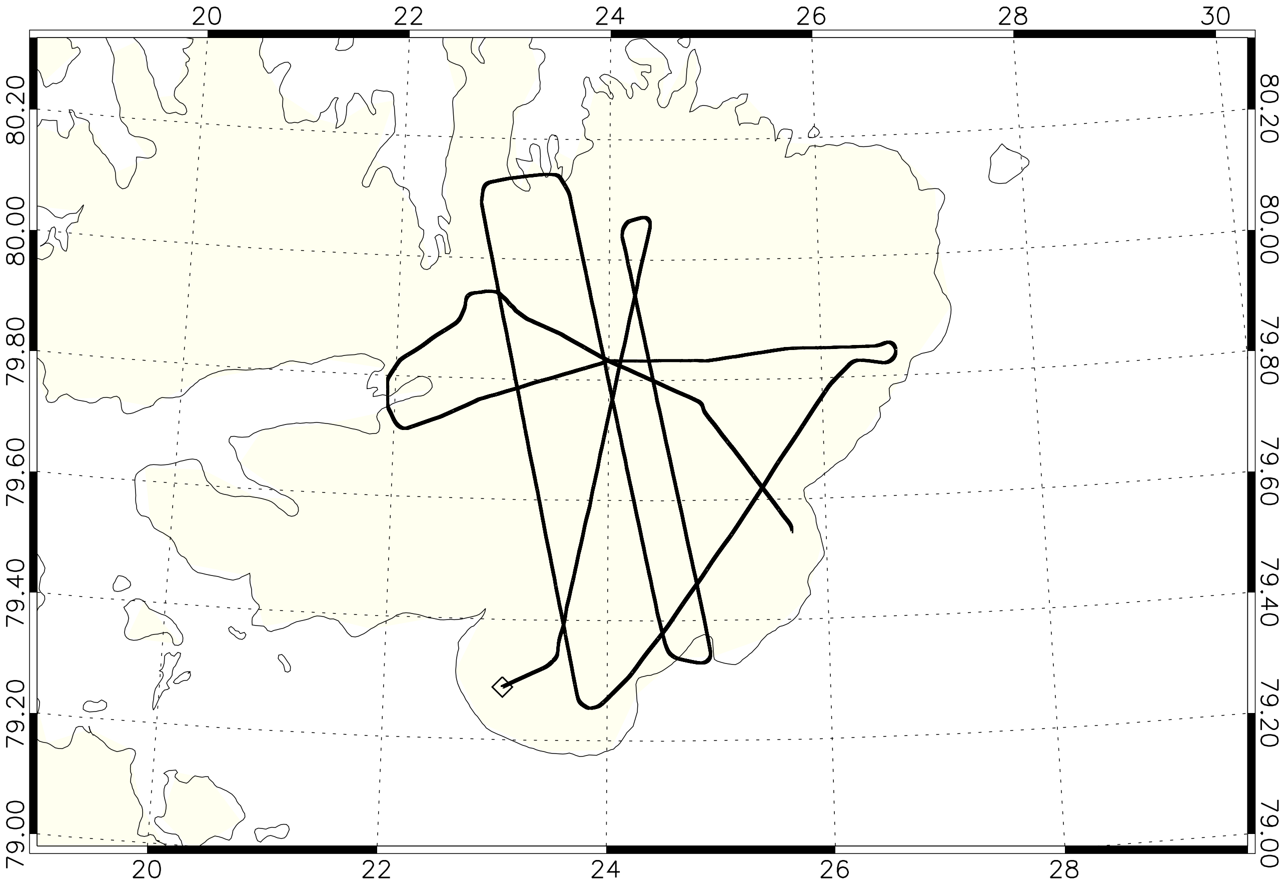


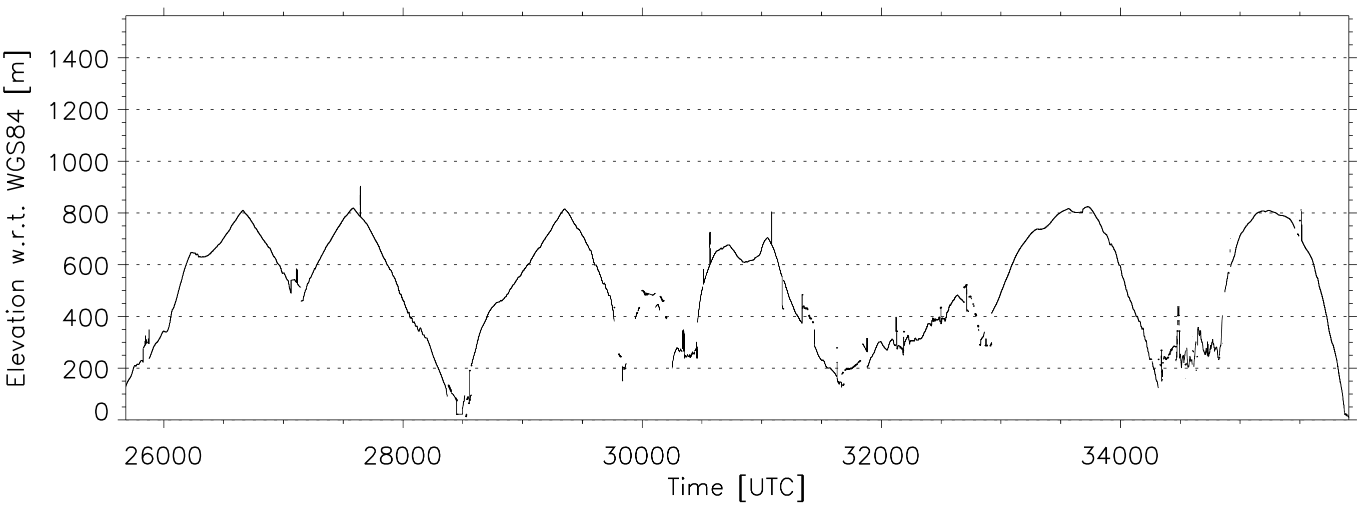


Date	2011-04-28	**Instrument Mode**	Adv. Low Altitude
Start Time	10:35:57 (38157)	**Aircraft**	DNSC Twin Otter
Stop Time	11:35:43 (41743)	**Retracker**	OCOG
Distance	236.159 km	**INS Resolution**	50 Hz
Duration	00 h 59 m 47 s	**Processor Version**	0403

A110430_01

AS30A01_ASIWL1B040320110430T070802_20110430T095830_0001.DBL

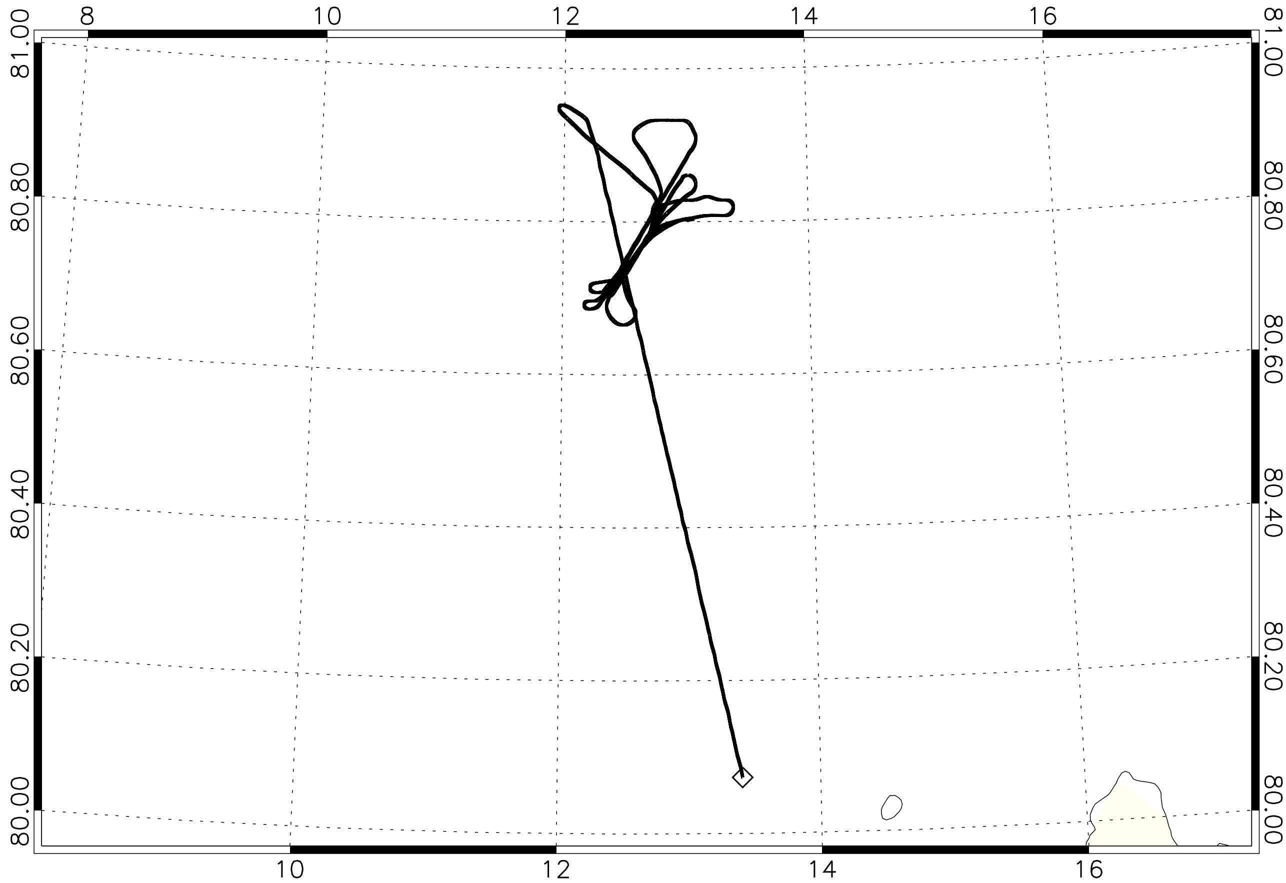


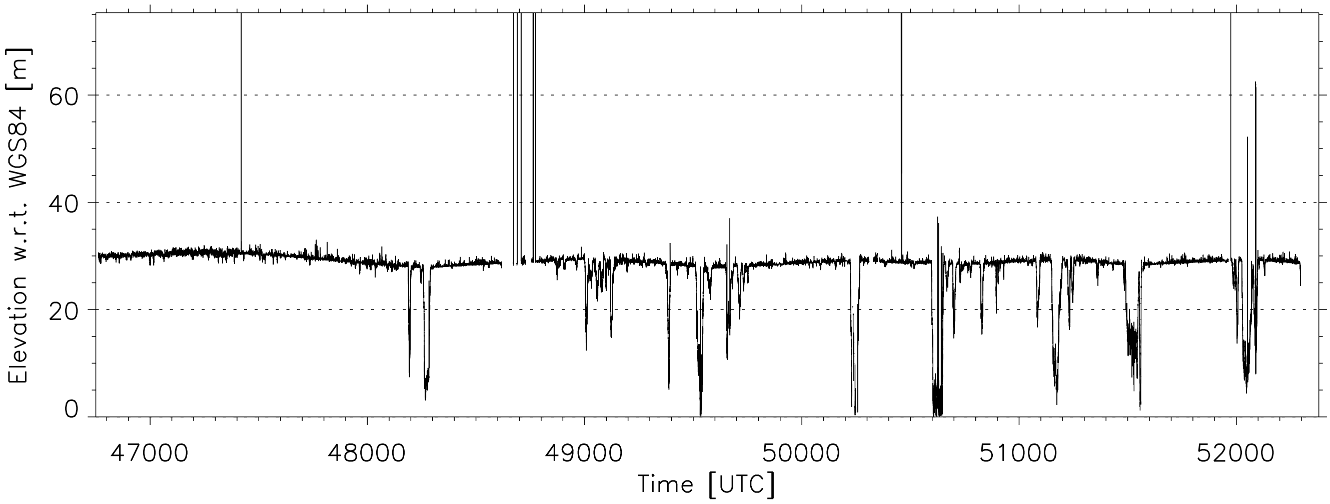


Date	2011-04-30	**Instrument Mode**	Adv. Low Altitude
Start Time	07:08:02 (25682)	**Aircraft**	DNSC Twin Otter
Stop Time	09:58:29 (35909)	**Retracker**	OCOG
Distance	688.077 km	**INS Resolution**	50 Hz
Duration	02 h 50 m 27 s	**Processor Version**	0403

A110430_02

AS30A02_ASIWL1B040320110430T125910_20110430T143300_0001.DBL

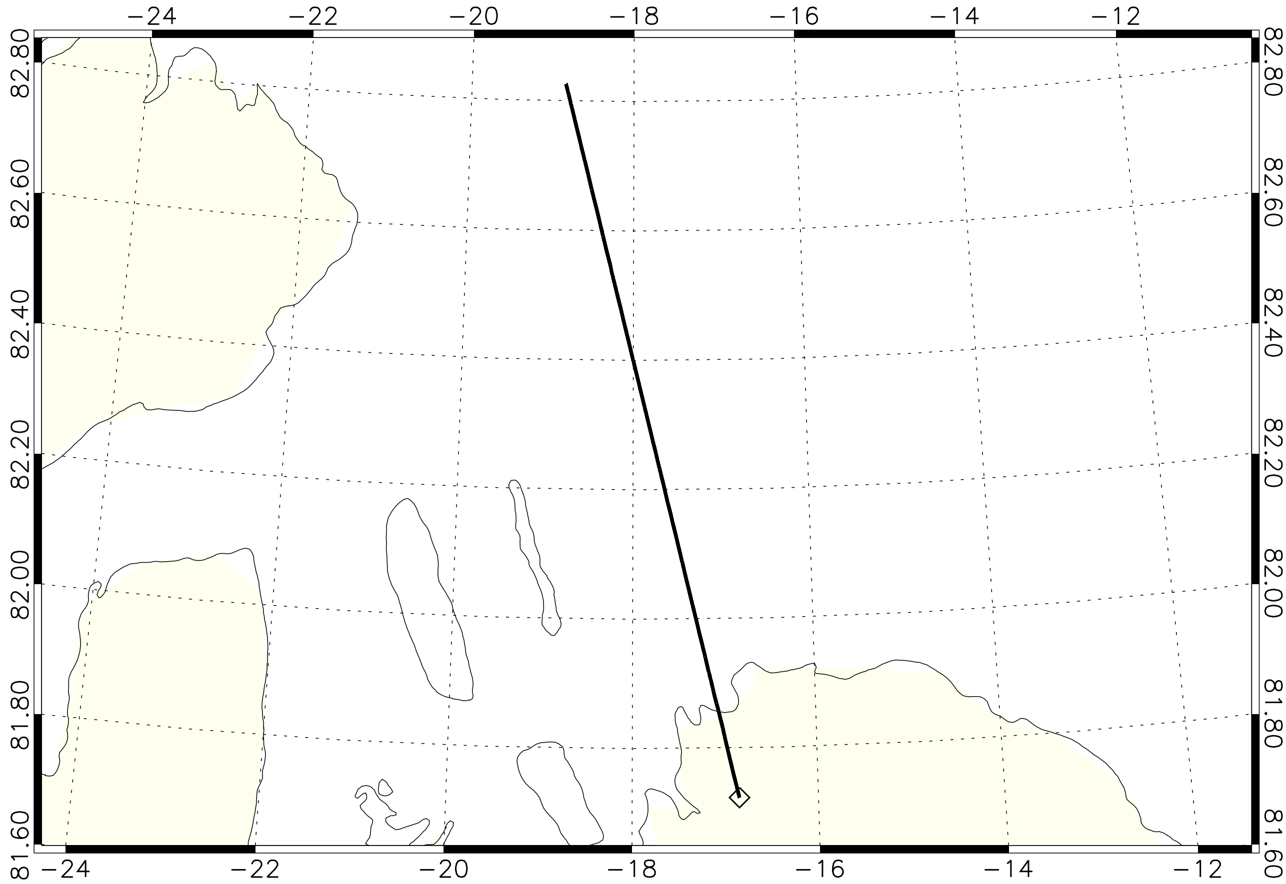


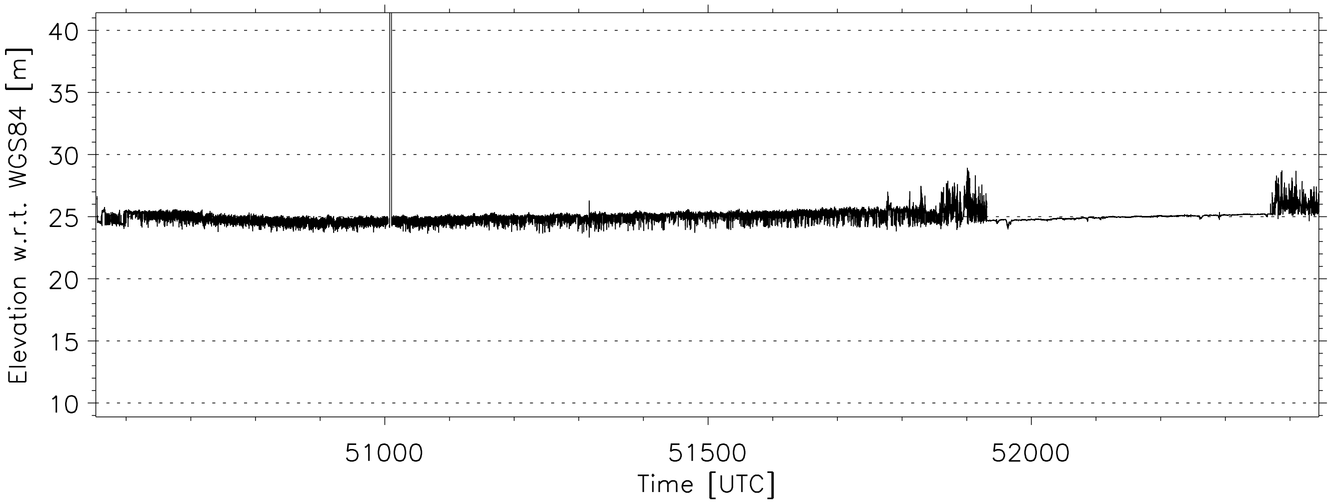


Date	2011-04-30	**Instrument Mode**	Adv. Low Altitude
Start Time	12:59:10 (46750)	**Aircraft**	DNSC Twin Otter
Stop Time	14:32:59 (52379)	**Retracker**	OCOG
Distance	339.088 km	**INS Resolution**	50 Hz
Duration	01 h 33 m 50 s	**Processor Version**	0403

A110502_01

AS3OA01_ASIWL1B040320110502T140233_20110502T142556_0001.DBL

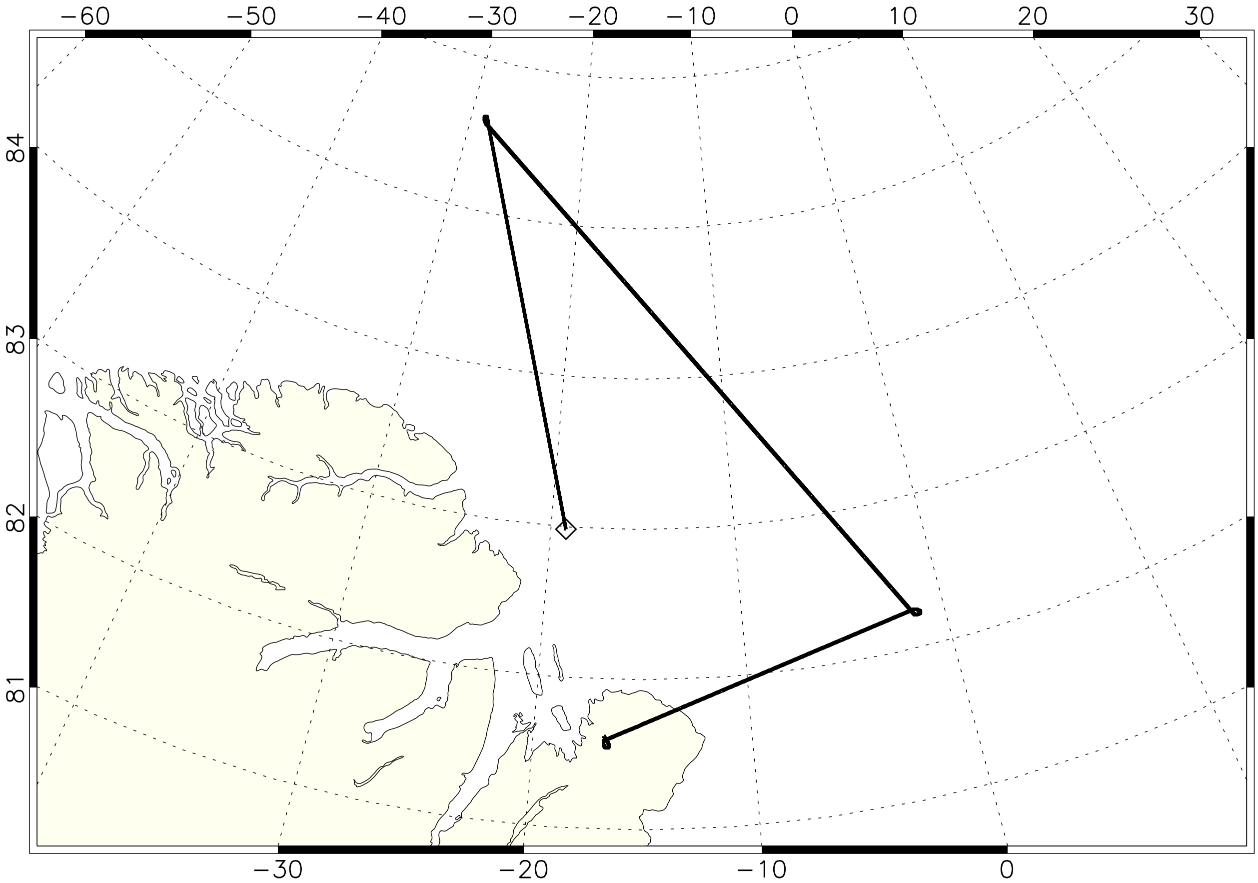


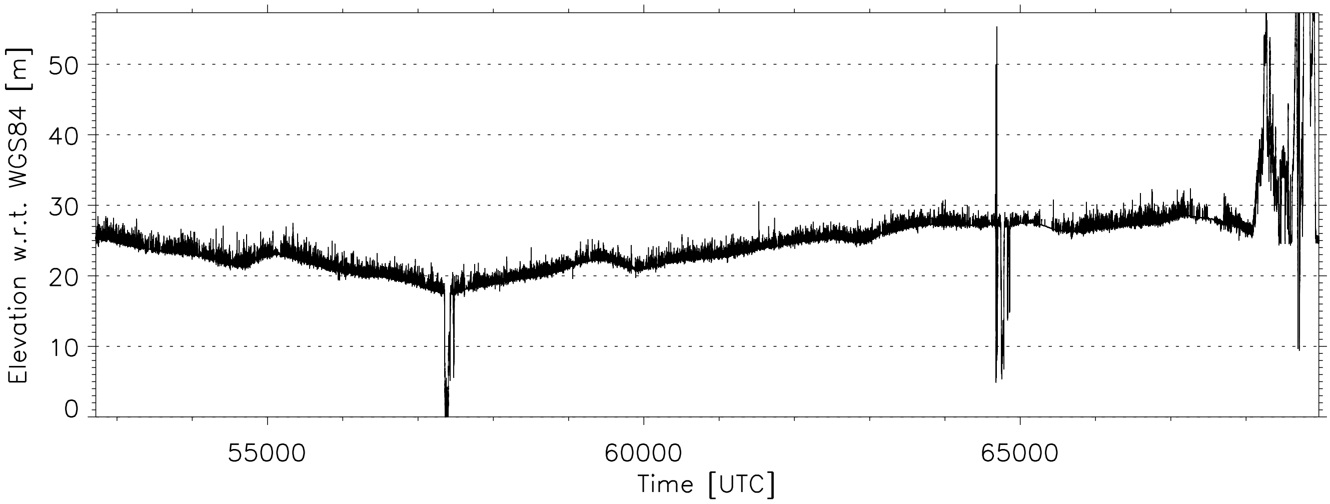


Date	2011-05-02	**Instrument Mode**	Adv. Low Altitude
Start Time	14:02:33 (50553)	**Aircraft**	DNSC Twin Otter
Stop Time	14:34:04 (52444)	**Retracker**	OCOG
Distance	126.222 km	**INS Resolution**	50 Hz
Duration	00 h 31 m 32 s	**Processor Version**	0403

A110502_03

AS30A03_ASIWL1B040320110502T143839_20110502T190928_0001.DBL

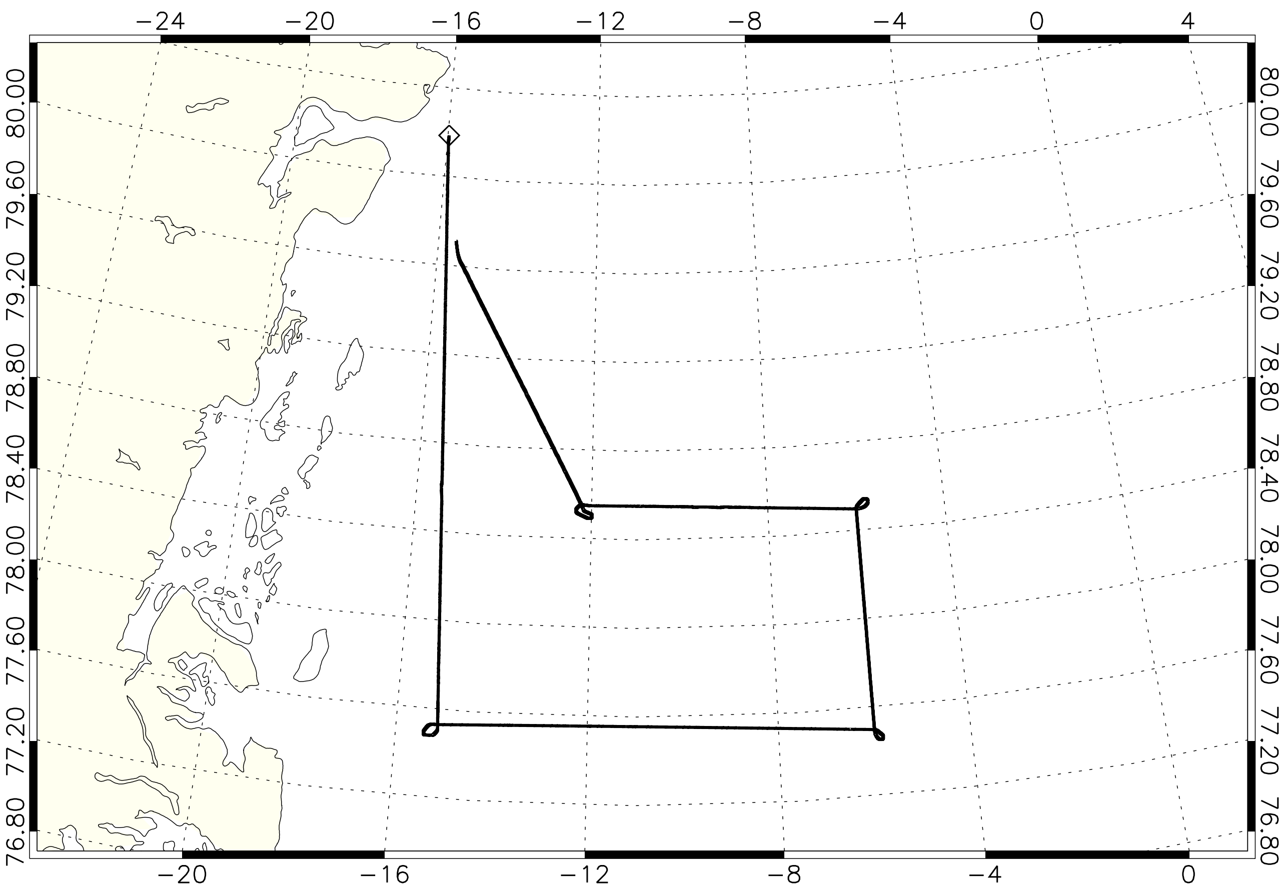


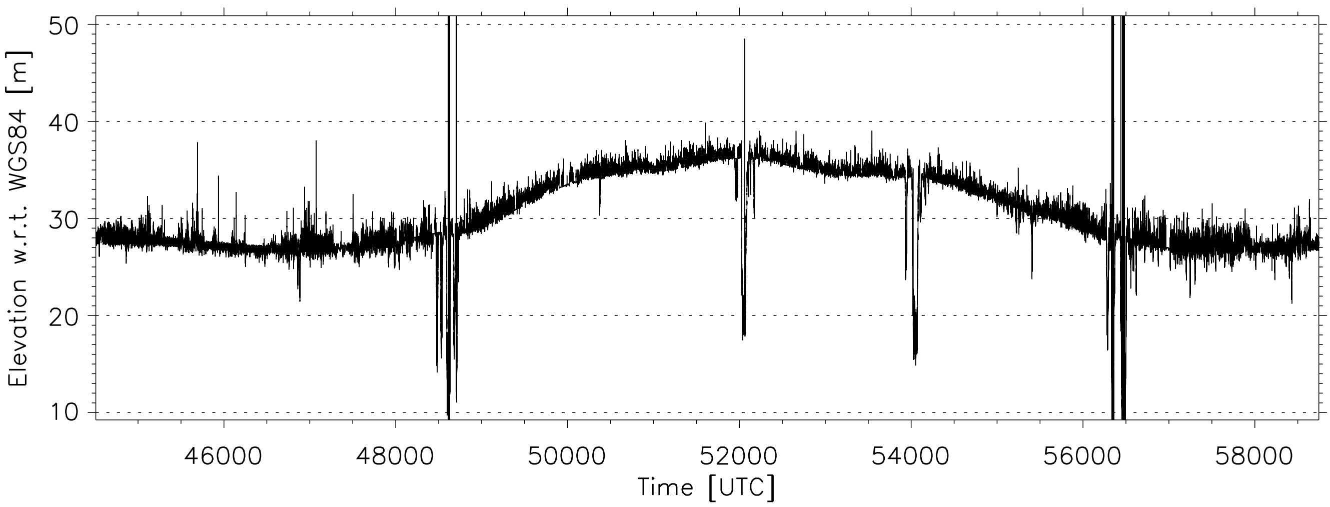


Date	2011-05-02	**Instrument Mode**	Adv. Low Altitude
Start Time	14:38:39 (52719)	**Aircraft**	DNSC Twin Otter
Stop Time	19:09:26 (68966)	**Retracker**	OCOG
Distance	1076.702 km	**INS Resolution**	50 Hz
Duration	04 h 30 m 48 s	**Processor Version**	0403

A110503_06

AS30A06_ASIWL1B040320110503T122149_20110503T161905_0001.DBL

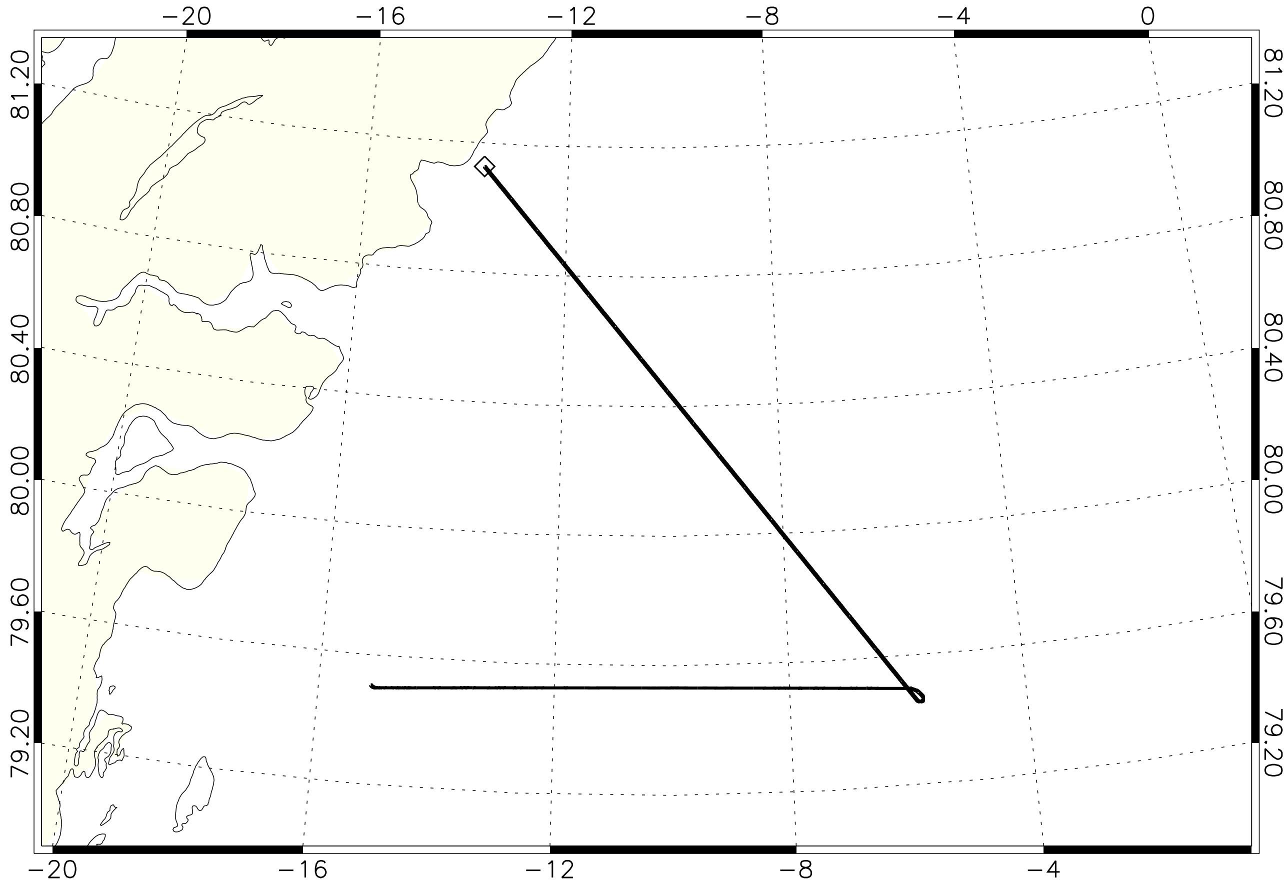


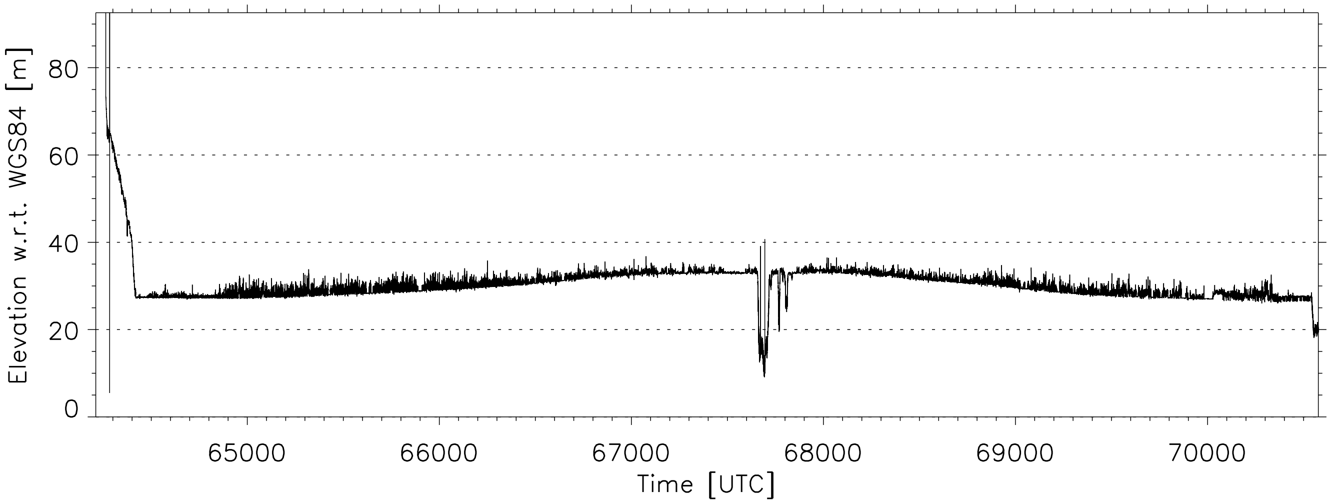


Date	2011-05-03	**Instrument Mode**	Adv. Low Altitude
Start Time	12:21:49 (44509)	**Aircraft**	DNSC Twin Otter
Stop Time	16:19:04 (58744)	**Retracker**	OCOG
Distance	988.331 km	**INS Resolution**	50 Hz
Duration	03 h 57 m 16 s	**Processor Version**	0403

A110503_07

AS30A07_ASIWL1B040320110503T175011_20110503T193617_0001.DBL

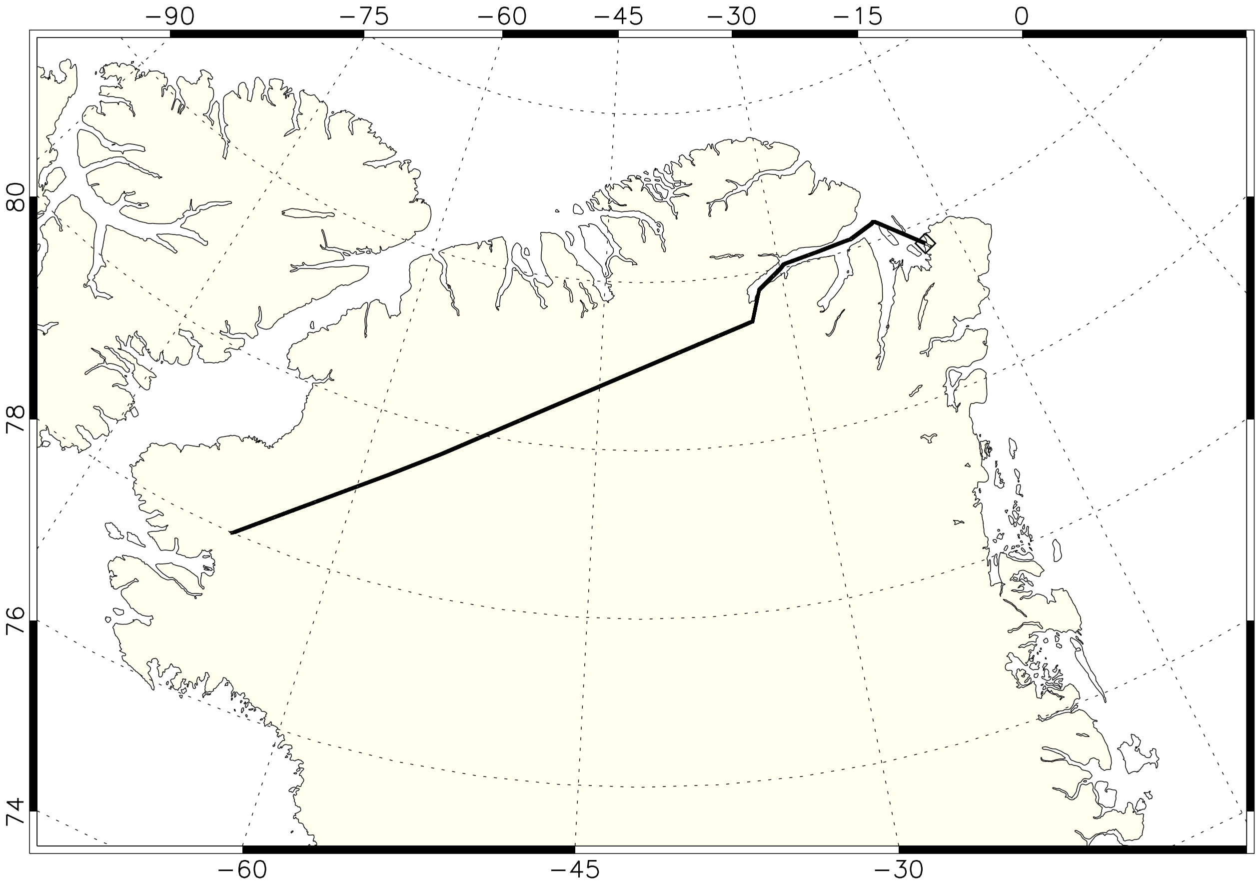


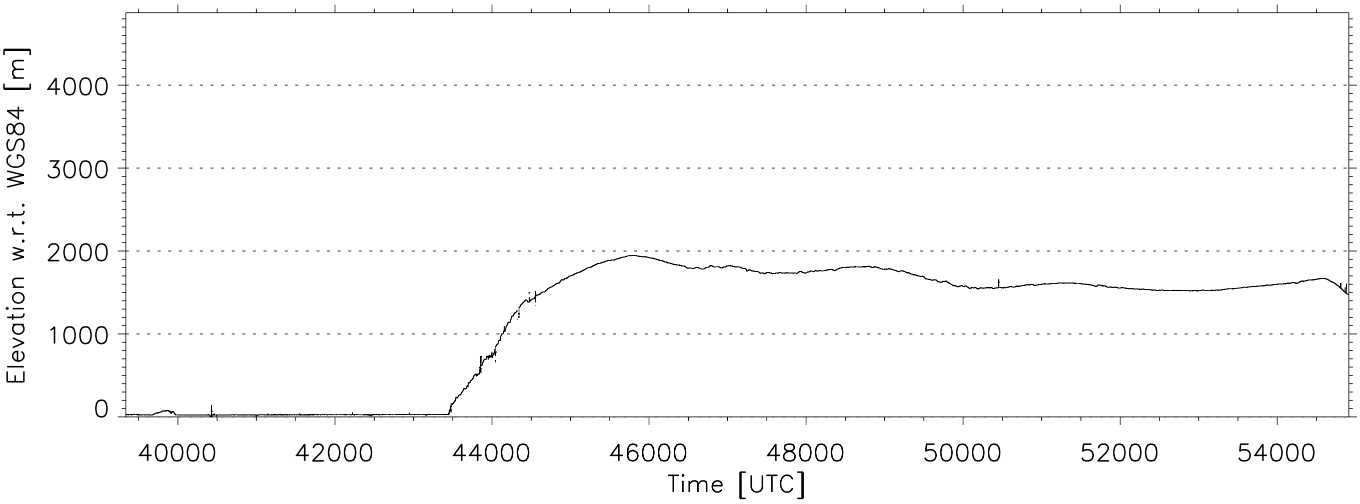


Date	2011−05−03	**Instrument Mode**	Adv. Low Altitude
Start Time	17:50:11 (64211)	**Aircraft**	DNSC Twin Otter
Stop Time	19:36:16 (70576)	**Retracker**	OCOG
Distance	429.845 km	**INS Resolution**	50 Hz
Duration	01 h 46 m 06 s	**Processor Version**	0403

A110506_00

AS30A00_ASIWL1B040320110506T105538_20110506T151515_0001.DBL

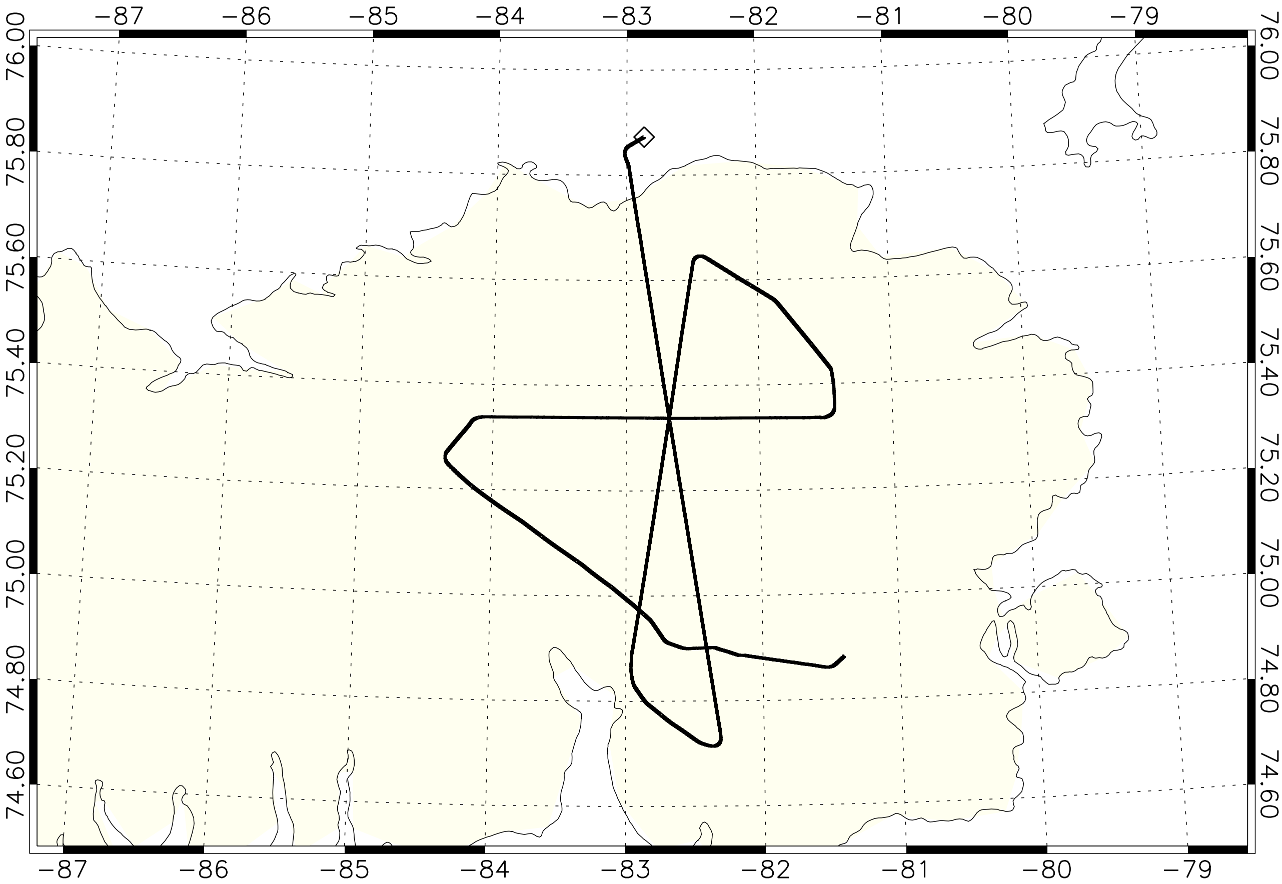


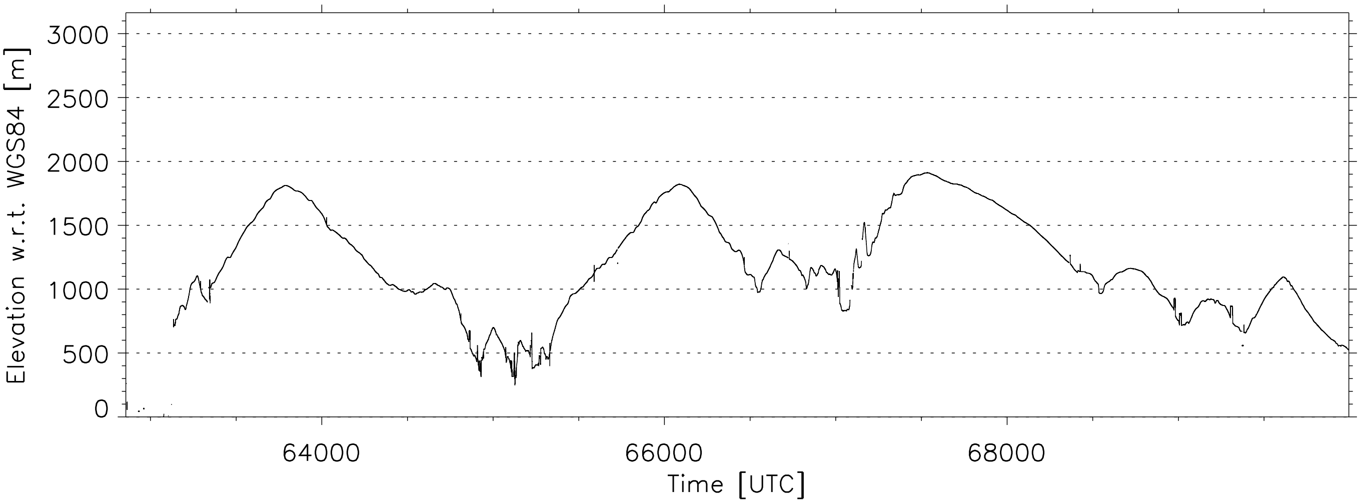


Date	2011−05−06	**Instrument Mode**	Adv. Low Altitude
Start Time	10:55:37 (39337)	**Aircraft**	DNSC Twin Otter
Stop Time	15:15:12 (54912)	**Retracker**	OCOG
Distance	1041.784 km	**INS Resolution**	50 Hz
Duration	04 h 19 m 35 s	**Processor Version**	0403

A110507_01

AS30A01_ASIWL1B040320110507T172736_20110507T192637_0001.DBL

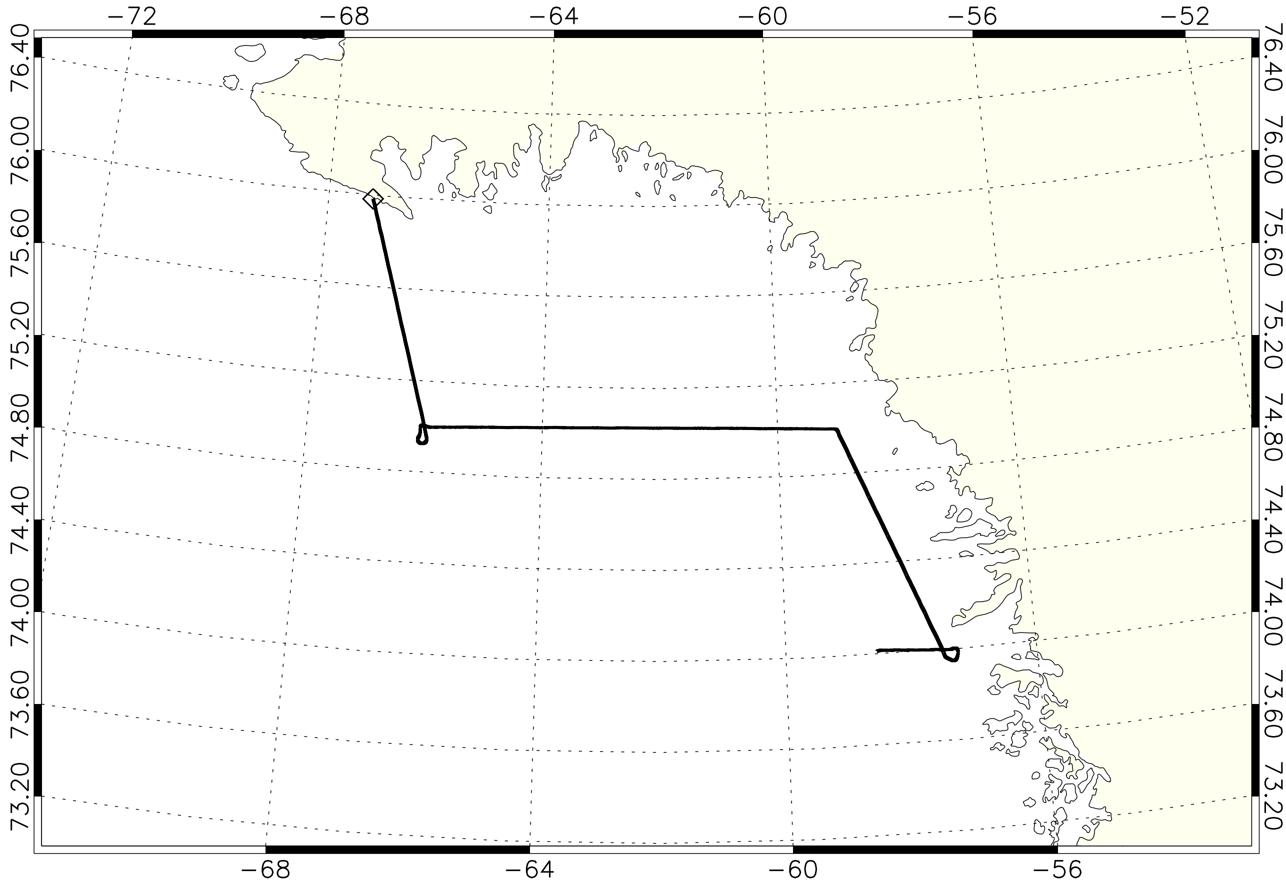


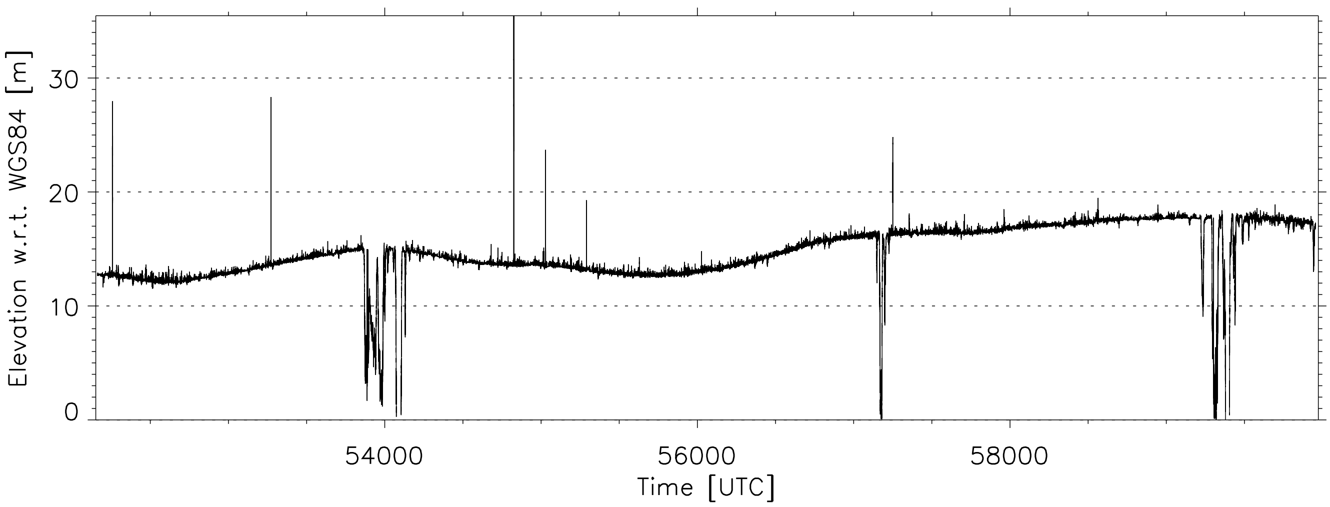


Date	2011-05-07	**Instrument Mode**	Adv. Low Altitude
Start Time	17:27:36 (62856)	**Aircraft**	DNSC Twin Otter
Stop Time	19:26:34 (69994)	**Retracker**	OCOG
Distance	482.149 km	**INS Resolution**	50 Hz
Duration	01 h 58 m 59 s	**Processor Version**	0403

A110508_00

AS3OA00_ASIWL1B040320110508T142911_20110508T163933_0001.DBL





Date	2011-05-08	**Instrument Mode**	Adv. Low Altitude
Start Time	14:29:11 (52151)	**Aircraft**	DNSC Twin Otter
Stop Time	16:39:32 (59972)	**Retracker**	OCOG
Distance	512.149 km	**INS Resolution**	50 Hz
Duration	02 h 10 m 22 s	**Processor Version**	0403

A110508_01

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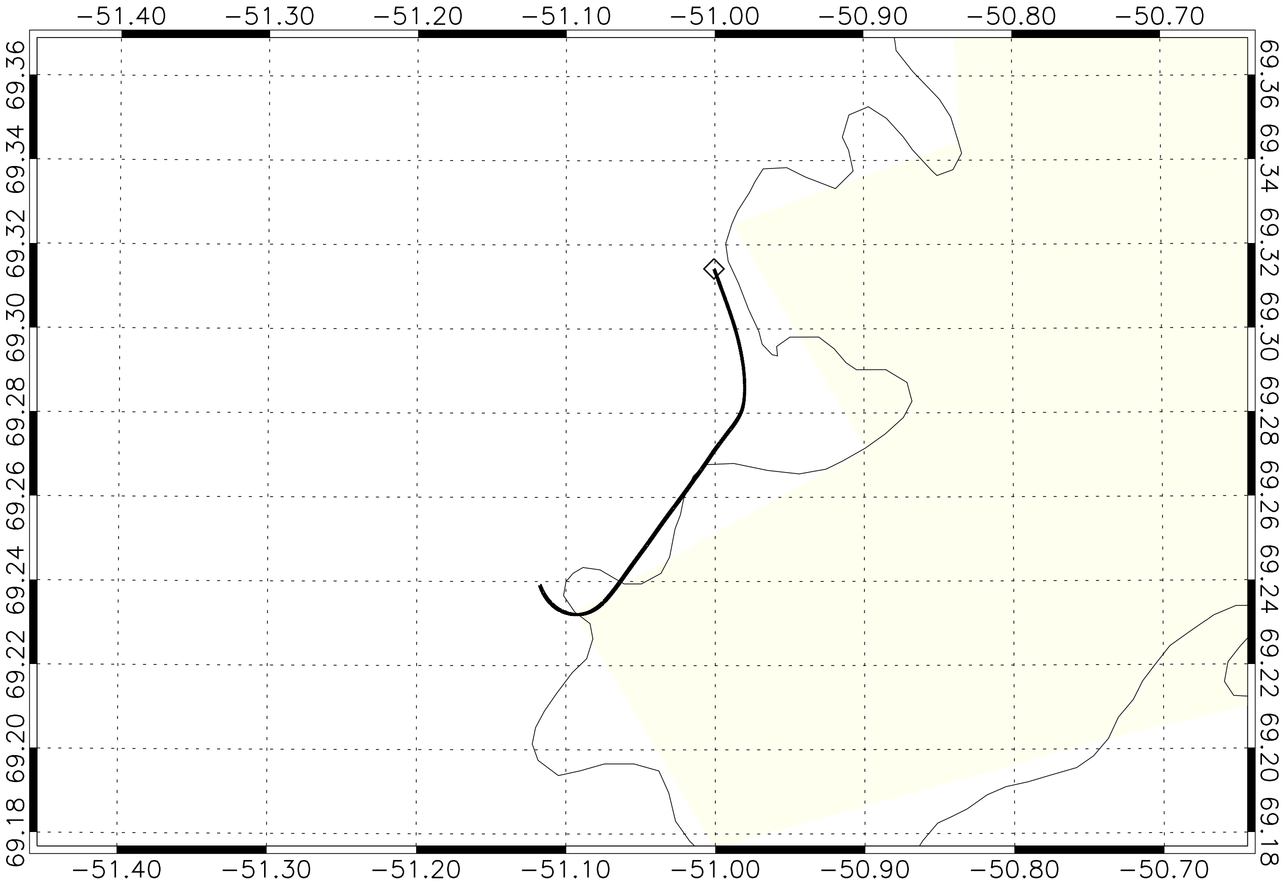

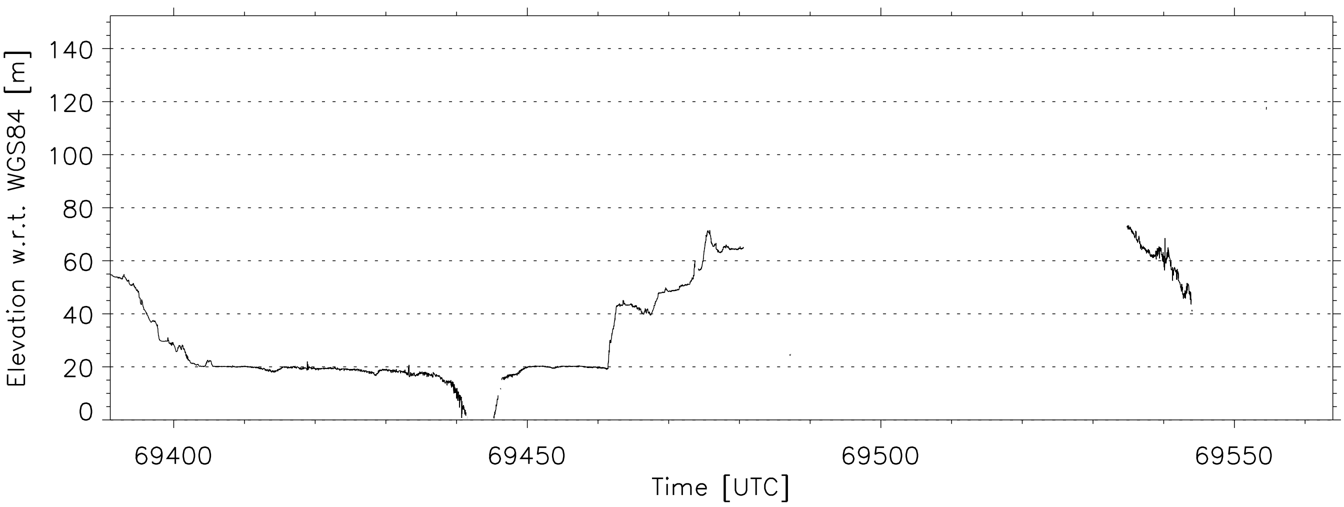

Date	2011-05-08	**Instrument Mode**	Adv. Low Altitude
Start Time	19:16:31 (69391)	**Aircraft**	DNSC Twin Otter
Stop Time	19:19:23 (69563)	**Retracker**	OCOG
Distance	12.303 km	**INS Resolution**	50 Hz
Duration	00 h 02 m 53 s	**Processor Version**	0403

A110509_01

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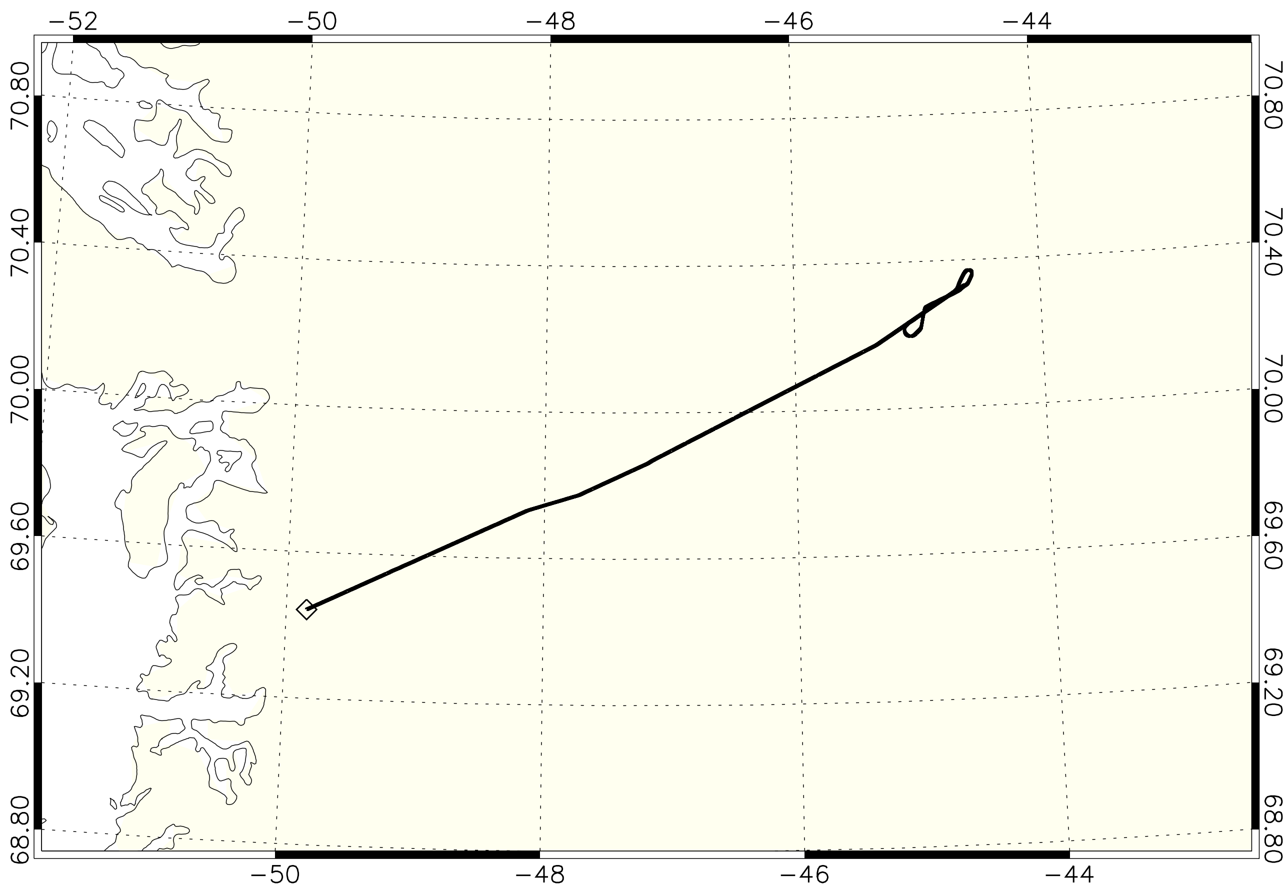
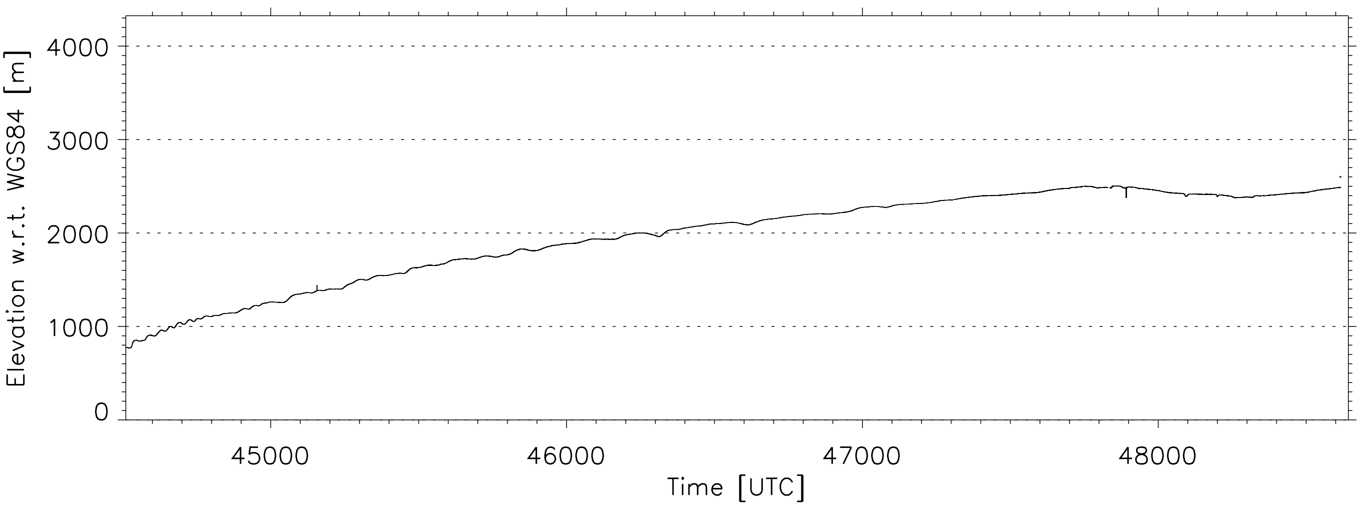
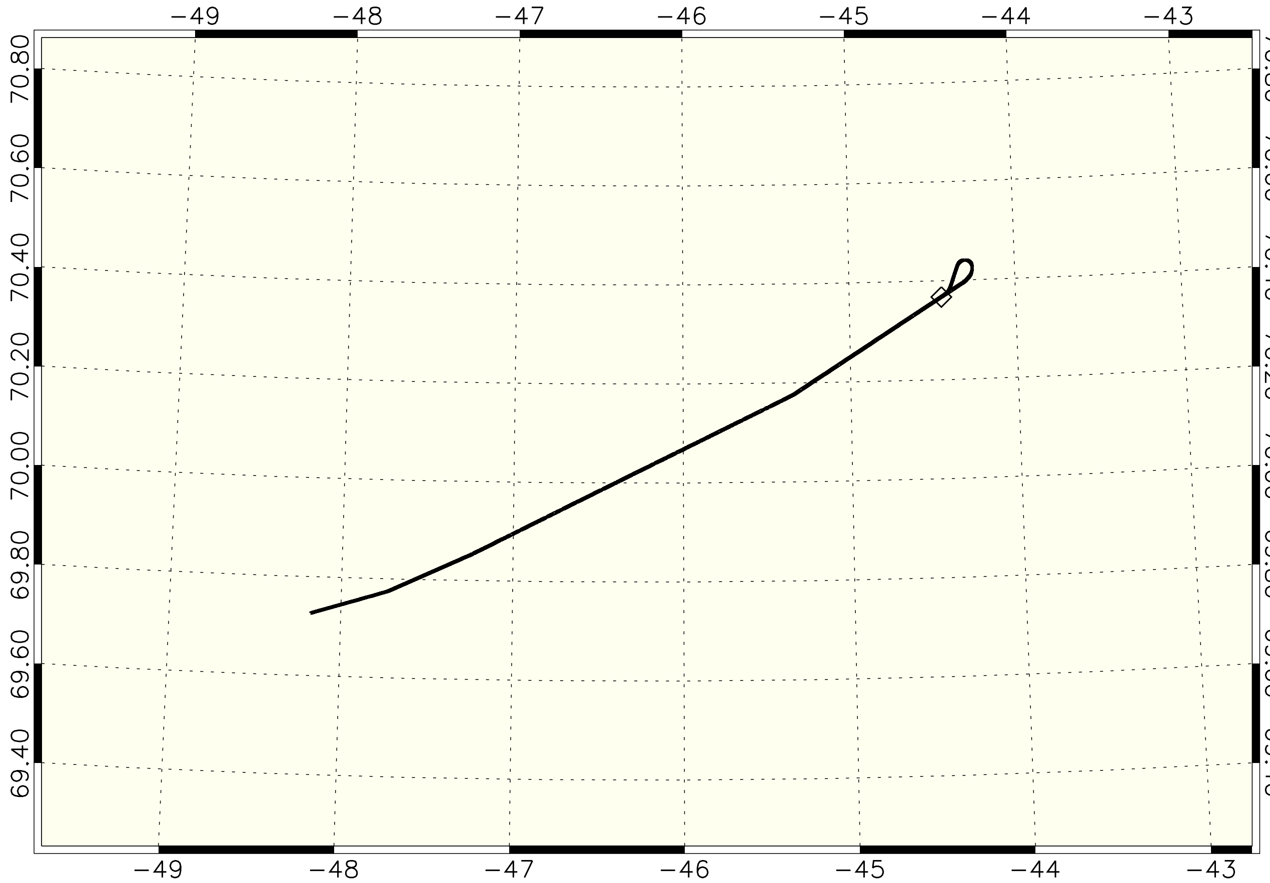


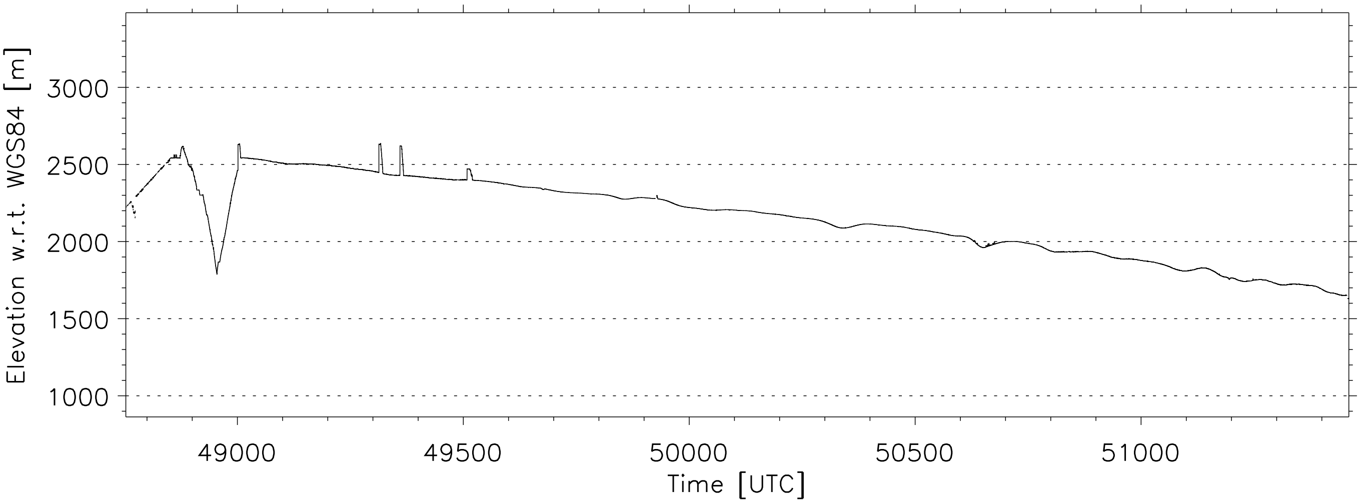


Date	2011-05-09	**Instrument Mode**	Adv. Low Altitude
Start Time	12:21:50 (44510)	**Aircraft**	DNSC Twin Otter
Stop Time	13:30:42 (48642)	**Retracker**	OCOG
Distance	284.429 km	**INS Resolution**	50 Hz
Duration	01 h 08 m 53 s	**Processor Version**	0403

A110509_02

AS3OA02_ASIHL1B040320110509T133233_20110509T141740_0001.DBL





Date	2011-05-09	**Instrument Mode**	High Altitude
Start Time	13:32:33 (48753)	**Aircraft**	DNSC Twin Otter
Stop Time	14:17:39 (51459)	**Retracker**	OCOG
Distance	181.991 km	**INS Resolution**	50 Hz
Duration	00 h 45 m 07 s	**Processor Version**	0403

10 APPENDIX Preliminary Science Flight Report, Operation IceBridge Arctic 2011

Preliminary Science Flight Report
Operation IceBridge Arctic 2011

Flight: **F20**
Mission: **Sea Ice CryoVEx**

Flight Report Summary

Aircraft	**P-3B (N426NA)**
Flight Number	020
Flight Request	11P006
Date	Friday, April 15, 2011 (Z)
Purpose of Flight	Mission Sea Ice CryoVEx
Take off time	10:21 Zulu from Kangerlussuaq (BGSF)
Landing time	18:28 Zulu at Kangerlussuaq (BGSF)
Flight Hours	8.2 hours
Aircraft Status	Airworthy.
Sensor Status	All installed sensors operational.
Significant Issues	None
Accomplishments	• Low-altitude survey (1,500 ft AGL) of CryoVEx ground survey line. First pass was at 1,000 ft AGL. • Completed 60 nautical miles of CryoSat-2 track 12 minutes after satellite passed overhead. • ATM, MCoRDS snow and Ku-band radars, gravimeter, magnetometer, POS/AV, and DMS were operated on the survey lines. • Accumulation radar was not operated today due to sea ice mission and high altitude. • Ramp pass at 18,500 ft AGL for ATM calibration.
Geographic Keywords	Lincoln Sea, Alert, Arctic Ocean.
ICESat/CryoSat Track	CryoSat-2 track 5399
Repeat Mission	None.

Science Data Report Summary

Instrument	Instrument Operational			Data Volume	Instrument Issues
	Survey Area	Entire Flight	High-alt. Transit		
ATM	☑	☒	☒	43.7 GB	None
MCoRDS	☒	☒	☒	1 TB	None
Snow Radar	☑	☒	☒	100 GB	None
Ku-band Radar	☑	☒	☒	100 GB	None
Accumulation Radar	☒	☒	☒	N/A	N/A
DMS	☑	☒	☒	27 GB	None
POS/AV	☑	☑	☑	2 GB	None
Gravimeter	☑	☑	☑	560 MB	None
Magnetometer	☑	☑	☑	420 MB	None

Mission Report (Michael Studinger, Mission Scientist)

Today's flight was a coordinated effort between ESA's CryoVEx campaign and NASA's Operation IceBridge. The CryoVEx 2011 teams are currently operating from CFS Alert and have installed corner reflectors and GPS buoys on the sea ice north of Alert yesterday using a Kenn Borek Twin Otter. Today and tomorrow, teams from the University College London and the University of Alberta are on the ice making in situ measurements along the profiles between the corner reflectors. A DC-3/BT-67 Basler from the Alfred Wegener Institute in Germany participates in the experiment with a towed EM bird for sea ice thickness measurements and a laser altimeter. The Technical University of Denmark is operating the ASIRAS radar, the airborne version of CryoSat's SIRAL radar on a Twin Otter. Today, we had all four aircraft operating on the same survey line to make measurements for comparsion with CryoSat-2, which was flying overhead. What a great day for sea ice research!

The NASA IceBridge teams participated by collecting data along a 0.5 km long profile, that will be survey tomorrow by the UCL team on the ground, which had installed the corner reflectors and GPS buoys yesterday. After transiting from Kangerlussuaq, we had enough time to fly 6 passes over the survey line making sure we got close enough within a few tens of meters to the corner reflectors. The visual aids have been invaluable and were clearly visible from 1500 ft and at 250 kts. On several of the passes we got closer than 10 meters to the corner reflectors and saw once a 25 dB increase in signal amplitude on the snow radar. The purpose of this experiment is to tie all the different measurements together and calibrate the CryoSat-2 measurements in cold conditions over sea ice. Today's data set of ground measurements, multiple airborne measurements with a comprehensive suite of instruments and a CryoSat pass will create a landmark data set to shed light on fundamental issues in remote sensing of sea ice. After finishing the 6 passes we had time to fly 60 miles of the CryoSat line before heading back to Kangerlussuaq. CryoSat-2 was passing overhead just 12 minutes before us.

Today was a great example of what can be accomplished when many organizations and nations work together. It was a great coordination effort. Well done everyone and in particular Jim from Ice Shelf Alert for coordinating all the traffic in the area today.

Individual instrument reports from experimenters on board the aircraft:

ATM: worked well and collected 43.7 GB data. 25.3 GB data were from high altitude.

MCoRDS: The MCoRDS system worked well and collected high altitude data over sea ice.

Snow and Ku-band radar: The snow and Ku-band radars collected 100% data along the line.

Accumulation radar: was not operated today due to sea ice and high altitude.

Gravimeter: Worked well. No issues.

Magnetometer: worked well.

DMS: worked very well and got images of corner reflectors on all passes.

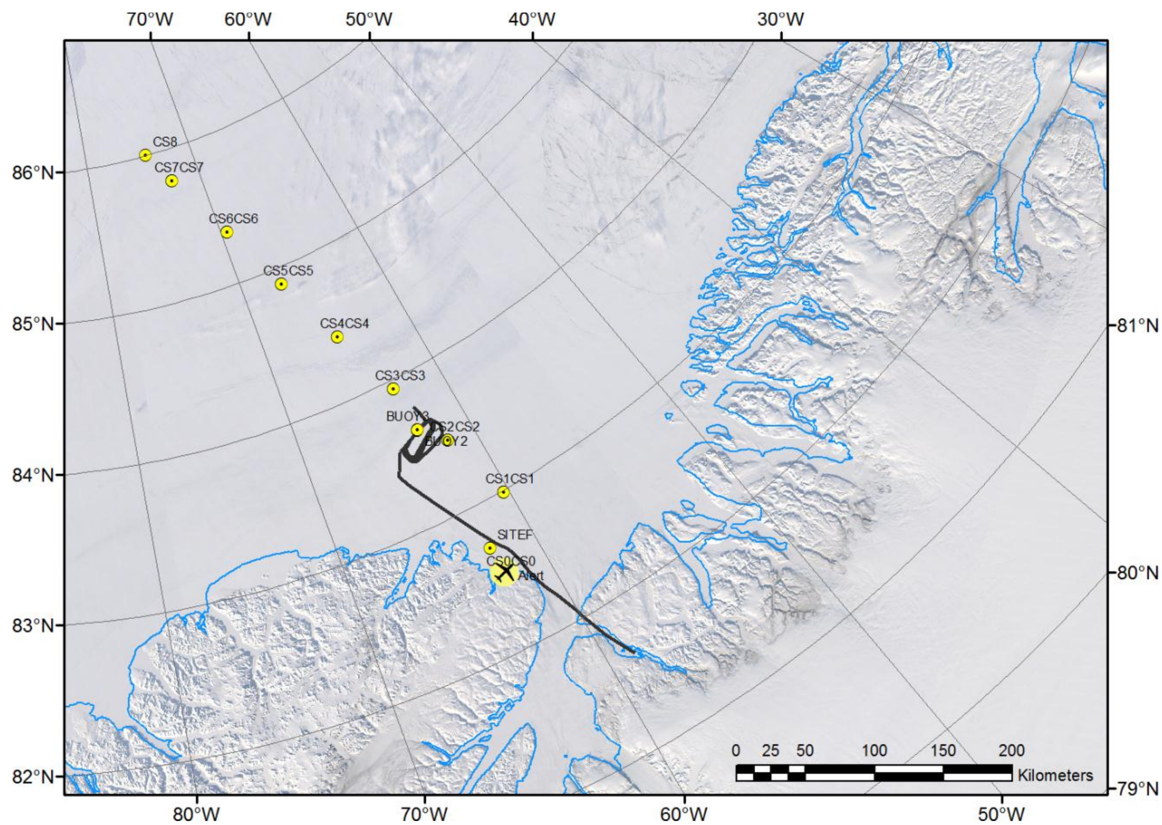


Figure 1: Mission plan for today's flight and segments of the P-3 trajectory.

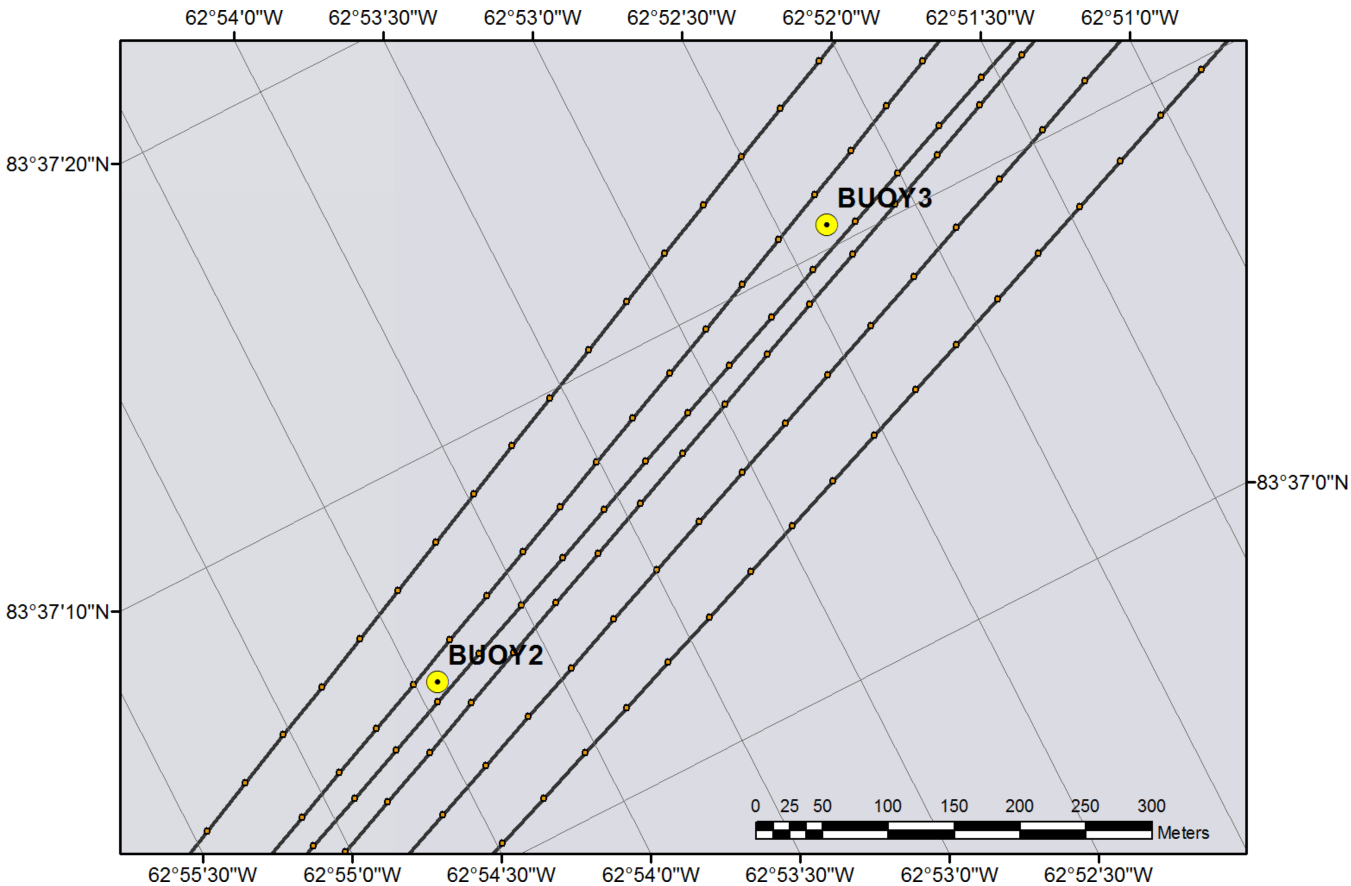


Figure 2: P-3 trajectory passing over the GPS buoys.

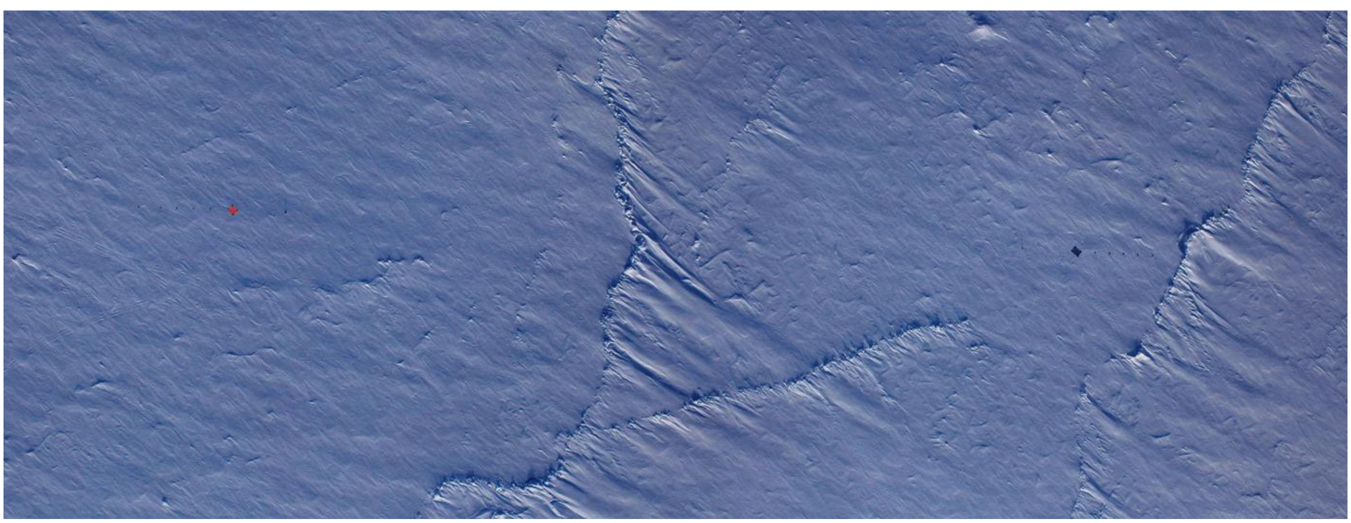


Figure 3: DMS image of survey line (450 meters long) between corner reflectors and GPS buoys.

Figure 4: DMS image of corner reflector and visual markers (5 x 5m in size).

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